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SPIN-OFF BENEFITS OF SPACE TECHNOLOGY

Study by the Secretariat

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BACKGROUND

1. The General Assembly, in its resolution 43/56 of 6 December 1988, requested the Committee on the Peaceful Uses of Outer Space to consider at its thirty-second session a new agenda item entitled "Spin-off benefits of space technology: review of current status". Since 1989, the Committee has considered that item at its annual sessions.
2. At its thirty-third session, in 1990, during its consideration of the agenda item, the Committee recommended that the Outer Space Affairs Division undertake a study of spin-offs, on the basis of information provided by Member States. 1/ The Committee also recommended that the Secretariat invite Member States to submit annual reports on their space activities, including information on spin-off benefits of space activities. 2/ That recommendation was brought to the attention of Member States in a note verbale from the Secretary-General dated 14 August 1990.
3. The present study has been prepared by the Secretariat in response to the recommendation of the Committee on the Peaceful Uses of Outer Space and is based on information received from Member States. While no information was submitted to the Secretariat specifically in response to the note verbale from the Secretary-General, information provided by Member States to the Committee during its consideration of the agenda item and published information from Member States have been used in preparing the present study. The study includes a variety of examples of spin-off applications in a number of fields and a review of the programmes of Member States and space agencies specifically concerning the identification and promotion of spin-off applications and benefits.
4. The purpose of the present study is to provide Member States with a review of the spin-off process and examples of actual and potential spin-off technologies, applications and benefits. The study is intended primarily for the benefit of countries that have not yet undertaken detailed studies of spin-offs or established programmes for promoting spin-off benefits and that may be interested in such activities. For countries that have undertaken such activities, the study may be useful as a survey of activities in other countries. Finally, the information in the study can be used as a basis for considering what the international community might do to promote access by all countries to the potential spin-off benefits of space technology.

I. TECHNOLOGY AND SPIN-OFFS

A. The definition of spin-off

5. Space technology is inseparable from technology used in a variety of other activities. While technology, for organizational and conceptual purposes, is commonly dealt with in terms of fields such as communications, data processing, metallurgy, optics, aerospace and many others, these

divisions are largely artificial and the fields substantially overlapping. Complex activities, such as space activities, are necessarily multi-disciplinary and involve a wide range of technical specialties. Space activities in general require advanced technology in such areas as lightweight and high-temperature metallurgy, combustion chemistry, high-frequency communications and high-speed data processing. In addition, particular space applications have other specific technological requirements, as for example the requirements for life-support systems and physiological monitoring for human space flight.

6. The technologies required for space activities have in many cases become available as a result of technological developments in other fields. In other cases, substantial innovation has been required to develop the new technologies required. In yet other cases, space activities have used technologies taken from other fields with only modest adaptations. The equipment, processes and knowledge developed for space activities are, in turn, applied, with varying degrees of adaptation, to a variety of non-space activities.

7. It is this application of a technology developed in one field, with or without adaptation, to a use in another field that is referred to as "spin-off". Spin-off applications are thus applications other than those for which the technology was originally designed. Spin-offs are generally, but not always, unplanned and unforeseen benefits of the technology development effort. The technology applied can take the form of equipment, of new materials, of processes or of more general know-how.

8. In studies of the benefits of space activities, the term "spin-off" is used in a number of ways. In particular, studies of government space programmes sometimes use the term to include not just applications of space technology to non-space uses, but also transfers of space technology from government research-and-development programmes to commercial space activities. The term is also sometimes used to refer to applications of space technology in such fields as resource mapping or telecommunications, even when the space technology was developed specifically for the purpose. More commonly, however, spin-offs are defined as secondary applications, as opposed to the primary applications usually referred to as space applications.

9. For the purposes of the present study, a spin-off application of space technology will be defined as a secondary application in a non-space field of a technology developed for primary use in space-related activities.

10. The transfer of technology from government space research-and-development programmes to industry, including space industry, is a closely related process that needs to be considered in a study of spin-offs for two reasons. First, much of the information on spin-offs comes from studies and programmes concerning transfer of space technology to commercial enterprises. And secondly, it seems likely that the transfer of space technology from government to industry promotes spin-offs since the industries concerned generally have non-space as well as space interests, thus facilitating the

transfer between fields. This transfer of technology will be discussed in particular in chapter III on promoting and managing spin-off applications.

B. The process of spin-off

11. Since the technologies that are used in space activities are generally closely related, and sometimes identical, to technologies used in non-space activities, developments in space technology generally have some potential applications for non-space activities, just as developments in related non-space technologies commonly have potential applications for space activities. These potential spin-offs can take various forms and can be attained either in the short or the long term. The benefits can take the form of new products or services, improved versions of existing products, less expensive products, the saving of lives or improved quality of life.

12. An illustrative historical example of the interaction of space and non-space technologies might be the photovoltaic technology used in solar panels. While the photovoltaic effect was observed by scientists in the nineteenth century, it was only in 1954, as part of semiconductor research, that the first practical photovoltaic technology was developed, a solar cell that converted sunlight to electricity with an efficiency of about 6 per cent. The early solar cells were so expensive, however, that they had virtually no economic applications.

13. With the beginning of the space age in 1957, photovoltaic cells, despite the high costs, provided the most cost-effective means of providing electrical power for satellites. The first solar-powered satellite was launched in 1958, and solar cells still power the vast majority of satellites. For many years, space activities generated a major part of the demand for photovoltaic technology and therefore provided much of the impetus for the further development of the technology, including new semiconductor materials, higher efficiencies and lower costs. In the 1970s, with the rapid increase in the cost of energy and the gradual decrease in the cost of solar cells, terrestrial applications became more economically attractive, generating further demand, technological improvement and cost reductions, which have in turn benefited space solar power systems.

14. This complex, continuing, interactive relationship between space technologies and other technologies is probably typical. Other historical examples would include micro-electronics, data processing, high-performance metallurgy, precision navigation and optical-electronic sensors as well as such management methods as project planning and risk analysis. While the general concept of spin-off applications is certainly valid in such cases, the continuing, interactive nature of the relationship is frequently too complex to allow any straightforward identification of a particular non-space application as a spin-off of a space technology or vice versa.

15. In the clearest, simplest and most easily identifiable cases of spin-off, a specific device, material or process developed for space activities is

directly transferred from a space programme institution, with the participation of programme personnel, to a non-space institution. It is such cases that provide most of the examples of spin-offs cited in the literature. In some cases, there may be formal recognition of the transfer, for example through the transfer of patent rights.

16. Most cases of spin-off, however, probably arise in less easily identifiable ways. Much of the development of space technology, for example, takes place in industry under contract to a government space programme. The contracting industries are generally not exclusively devoted to space and have non-space activities as well. Transfers of space technology to other fields within industrial enterprises undoubtedly occur frequently, but without public knowledge. In other, even less identifiable cases, an engineer in a non-space field may be inspired by a description of a space technology in a technical article, conference lecture, patent application or other source and may apply the idea in the non-space field. Another form of spin-off is the movement of personnel, along with their knowledge and skills, from space programmes to other activities. The space-related knowledge and skills will then be adapted and applied in the new activities, often without any particular awareness that a transfer of technology between two fields is taking place. Due to the close association of space activities and aviation activities in both government and industry, and their combination in aerospace vehicles, spin-offs between these two fields are particularly common.

17. Studies of spin-off applications and the spin-off process, however, suggest that the organizational separation of government space programmes from industry, of space industry from other industries and even of space divisions from other divisions with an industrial enterprise limit the spin-off applications of space technology. It would appear therefore that there are large potential spin-off benefits that are not currently being realized.

18. The examples of spin-off applications given in the present study are reasonably representative of the examples cited in the literature. Owing to the complexities in the spin-off process and the context in which spin-offs are studied, however, these examples are far from comprehensive and probably do not represent the relative importance of spin-offs in different fields. It has been estimated that there are tens of thousands of products and processes that have emerged as spin-off applications of space technology and have contributed some measure of economic, social or cultural benefit. 3/ These spin-offs cover so broad a range of needs and conveniences that it is difficult to find an area of everyday life they have not influenced. It should be understood, therefore, that the examples of spin-off applications described in the present study offer only a few illustrative cases of spin-offs in which the relationship between the space technology and the non-space spin-off is relatively clear and straightforward.

C. The study of spin-offs

19. Spin-off applications of technologies have been taking place as long as there have been technologies. The spin-off process often occurs without planning or awareness. Until recently, scientific and technological research and development were generally undertaken purely for their own sake or for the sake of the direct and intended benefits. Spin-offs occurred and may occasionally have been casually recognized, but were not generally considered a matter of interest or concern.

20. In recent years, the status of science and technology, and public attitudes towards them, have been changing. Technology is playing an increasingly important role in people's lives, and perhaps for that reason people have begun to look more carefully and critically at the implications of scientific and technological change. As expenditures on scientific research and technological development have increased, the public and politicians have begun to examine public expenditures on science and technology more closely. Scientific and technological institutions and programmes have therefore been under greater pressure to justify their activities and proposals in terms of economic and social benefits.

21. As demands for economic justifications for public spending on space activities increased, space agencies attempted to identify and evaluate the economic benefits of their activities. The resulting studies often revealed that spin-off applications provided an important part of such benefits and needed to be included in any comprehensive cost/benefit analysis. They also suggested that while spin-off benefits had occurred without institutional programmes or planning for that purpose, the benefits could probably be increased by organized spin-off or technology-transfer programmes established for the purpose.

22. Studies of space technology spin-off applications and processes have therefore been undertaken in recent years by a number of national and regional space programmes. It appears that these studies are generally undertaken for two purposes: (1) to identify the economic and social benefits of spin-off applications of space technology as part of an effort to identify all of the benefits derived from space programmes; and (2) to promote spin-off applications by identifying potential spin-off applications and actively working to transfer them to organizations that can develop, apply and distribute them. The results of these studies have been published and publicized to serve both of these purposes: to build public support for space activities by providing information on their benefits for everyday life, and to make workers in other fields aware of space technologies that might have spin-off applications in their field. Further studies are sometimes undertaken to assess the effectiveness of programmes established to promote spin-offs.

23. The pressure for cost/benefit studies to justify space activities has tended to be greatest for government programmes that are expensive and for which the economic and social benefits are indirect and difficult to define,

such as human space flight. In the case of commercial space activities such as satellite communications, on the other hand, the commercial, self-financing character of the applications is commonly seen as economic justification and there has been less concern with studying and promoting spin-off applications, although the potential and actual spin-offs are probably at least as great as in the non-commercial space activities.

24. As a result of the concentration of spin-off studies on publicly funded programmes with indirect benefits, the spin-offs cited in the literature tend to be quite selective. The large number of identified spin-offs from human space flight, notably in the areas of health and medicine, and the small number in the area of communications probably represents the emphasis of the studies and the nature of the spin-offs rather than the relative economic importance of the spin-off applications in the two fields. The selective nature of the studies underlines the difficulty of carrying out a comprehensive survey of spin-off benefits and indicates the partial nature of the benefits identified in the present study.

25. While most studies of spin-off benefits have been qualitative, there have been attempts at quantitative analyses. A study prepared for the National Aeronautics and Space Administration (NASA) of the United States of America, for example, attempted to quantify the economic effects of commercial spin-off applications of NASA technologies as reported in NASA's annual publication Spinoff. Some 441 commercial applications reported between 1978 and 1986 were traced, yielding 368 applications that had resulted in contributions to commercial sales and production cost savings and 259 applications for which the companies concerned could provide quantitative financial estimates. The companies reported an estimated \$21.3 billion in sales of new or improved products and an estimated \$315 million in cost savings. The study calculated that this commercialization of NASA technology produced federal corporate income tax revenues of nearly \$356 million. An estimated 352,000 jobs were created or saved. The largest benefits were in the field of transportation, including aviation, with industrial applications second and medical applications third. 4/

26. The European Space Agency (ESA) has undertaken two studies of the indirect economic effects of ESA industrial contracts, one in 1980, covering contracts during the period 1964-1976, and a second in 1988, covering contracts in the period 1977-1986. The 1988 study found that ESA contracts amounting to about \$4 billion had created industrial capabilities generating about \$12 billion in additional sales, of which about \$2.5 billion was for non-space, i.e. spin-off, products and services. Among the non-space activities, aviation and military sales had the largest spin-off effects, followed by data processing, electronics, medicine and telecommunications. Comparison of the 1980 and 1988 studies indicates that the commercial space activities stimulated by ESA contracts tripled between the two periods, while the non-space commercial activities remained about the same and declined relative to the total value of the ESA contracts. The study concluded that the ESA contractor companies were not organized in a way that facilitated transfer of space technology to their non-space activities and that the

development of commercial space activities in the 1980s had increased the separation of space and non-space activities within the companies. 5/

27. A study of the spin-off value of space research undertaken by the German Space Agency traced some 3,000 space technology patents filed since 1975, by means of a search for citations of these patents in scientific and commercial literature to determine if they had found use in other industries. According to the study, telecommunications received the most benefit from space patents, with the coating, textiles, machine-tool and process-engineering industries also making considerable use of space technology. The study also found applications of space technology in the inorganic chemistry, polymer processing, optics and construction industries. In the field of robotics, according to the study, much of the early research and development was related to space activities, with industrial applications benefiting from spin-offs. More recently, however, the robotics technology in different fields has become so specialized that direct spin-offs from one field to the other are increasingly rare. 6/

28. The recognition that the spin-off benefits of space technology were important and that there were large numbers of potential spin-off applications that were not being realized led to the establishment of programmes to identify technologies with potential spin-off benefits and to actively promote their adoption and commercialization by appropriate enterprises or agencies. While the greatest amount of work in this area has been done in the United States, and particularly by NASA, efforts have also been made in India and the Union of Soviet Socialist Republics and by ESA. Because of the extensive literature on the subject of spin-offs published in the United States, most of the examples in the present report are taken from the United States space programme. This does not indicate that spin-offs are less important in other space programmes, but only that there is less information available.

II. EXAMPLES OF SPIN-OFF APPLICATIONS

A. Medical monitoring and diagnosis

29. The requirement for careful monitoring of the medical condition of crews during space flight, both for the protection of their health and for the scientific study of the physiological response to weightlessness, has resulted in a variety of physiological monitoring techniques that are directly transferable to medical monitoring and diagnosis on Earth. Over the years, there has been a steady expansion and improvement in the range of medical equipment developed to study human reactions to the conditions of space flight. Benefits for clinical medicine have also derived from technology developed for monitoring ground simulations of the effects of weightlessness, for example by prolonged bedrest.

30. One of the most serious problems of prolonged human space flight is the redistribution of calcium and loss of bone mass during prolonged space flight resulting from the absence of the normal pressures and stresses due to

gravity. To monitor the condition of bones, a practical, inexpensive, non-invasive technique for taking quantitative measurements of bone stiffness and mass has been developed in the United States. Another device developed for monitoring bone loss is an implantable calcium ion sensor, which can indicate the decalcification of bones without the usual blood sample collection and laboratory analysis. These bone monitoring techniques have spin-off applications to the common problem of osteoporosis in elderly people. Where bone loss is detected, countermeasures developed for space crews, including exercise and pharmaceutical treatments, may also be applicable on Earth.

31. For monitoring the general condition of crews during space flight, an ingestible "temperature pill", accurate to one hundredth of a degree, has been developed. This device, which is the only available means of measuring deep-body temperatures, enables doctors to accurately diagnose and treat dangerously high or low body temperatures. The device incorporates several aerospace technologies, including integrated circuit miniaturization, sensor and microbattery techniques and telemetry technology. Work is proceeding on a four-channel ingestible capsule that will monitor temperature, heart rate, inner-body pressure and acidity. The new capsule will also be directly applicable for medical diagnostics on Earth.

32. A portable X-ray instrument, the Lixiscope (Low Intensity X-ray Imaging Scope), was developed in the United States space programme for use during space flight. This self-contained, battery-powered device produces an instant image on a fluorescent screen using radiation from a small amount of iodine 123, a short-lived radioisotope. The sensitivity of the screen allows the system to operate with less than 1 per cent of the radiation required by conventional X-ray systems. The device is now being produced commercially as an industrial tool to detect invisible cracks or flaws, allowing rapid quality control without waiting for the development of X-ray film. The unit's portability also allows it to be used for emergency medical diagnosis, for example for rapid detection of bone injuries in emergency rooms.

33. The computer image-enhancement techniques developed to process and analyse space imagery have been applied in a variety of other areas, particularly in medical imaging to provide "thematic maps" of the human body as a guide to diagnosis and treatment. Magnetic resonance imaging, for example, employs magnetic fields and radio waves to observe the chemical environment inside the body, but the raw data are in a form very difficult to interpret. Computer image-enhancement techniques are used to generate images of the body and to highlight differences in the tissues, making such problems as tumours or blood clots stand out clearly.

34. For monitoring blood circulation during weightlessness, an instrument known as the Ekhozasokop has been developed in the Soviet space programme for measuring, displaying and recording blood flow to the brain. This device has spin-off applications in medical research, for neurological diagnosis and for neurosurgical treatment when there is a need to monitor the dynamics of blood flow to the brain, to organs and in the main blood vessels. Since the instrument is portable, it can also be used in ambulances.

35. The Argument instrument, also developed in the USSR, scans the heart and major blood vessels by means of ultrasound in order to monitor the condition of the heart and its chambers and the major blood vessels, including the functioning of the heart valves and cardiac muscle. This portable instrument can be used for rapid, detailed and accurate diagnosis of cardiovascular disease in clinics and ambulances.

36. A variety of medical monitoring instruments developed for the Soviet space programme have been combined into the "Ecosan" automated mobile technical laboratory for conducting general medical examinations. Such exams, when conducted on large numbers of people, provide not only information important to those individuals, but also a profile of the health of the population in particular geographic areas or industrial occupations. Combining these profiles into maps of medical-ecological conditions can reveal the influence of environmental conditions, including pollution, on public health.

B. Medical treatment

37. The micro-electronic and telemetry technology developed for space activities has been used for the treatment of heart disease, the leading cause of death in many industrialized countries. Micro-electronic pacemakers, which generate an electrical pulse to ensure a regular heartbeat in people with heart defects, were an early product of United States space programmes. In 1979, a programmable pacemaker was introduced, and recently a system with two-way telemetry capability has been developed. This new system allows a physician to receive information from and transmit instructions to a patient's pacemaker using wireless telemetry, so that the pacemaker impulse can be fine-tuned to meet each patient's individual needs.

38. A microprocessor-based monitoring system, based on space technology, is being used in an advanced portable defibrillator and an automatic implantable defibrillator to deliver a balanced electric pulse to restore normal heart rhythm in the case of a disruption of the normal heartbeat. The implantable device can reduce the large number of deaths due to ventricular defibrillation that follow initial heart attacks. The portable defibrillator is being used in emergency situations to revive heart attack victims.

39. Another spin-off from space research of benefit to people suffering from heart disease is the use of lasers and fibre optics for treating obstructed coronary arteries without surgery. A small fibre-optic catheter is threaded through blood vessels to the coronary arteries from which it carries an image of the arteries back to a video screen. When an area of atherosclerotic plaque build-up in an artery is identified, high-power laser pulses are delivered through the fibre optics to break up and burn away the plaque and clean the clogged arteries very precisely without surgery. The burning process occurs so quickly that neighbouring tissue is not damaged.

40. Motion sickness in space, as on Earth, is not particularly dangerous but can be very unpleasant and even incapacitating, and efforts have been made to protect space crews from this effect. A feedback training procedure has been developed in the United States to enable people to learn to regulate their autonomous nervous systems so as to prevent the nausea of space motion sickness. These feedback techniques may also provide a countermeasure for chemotherapy-induced nausea and vomiting in cancer patients. To analyse the physiological changes and time-course of motion sickness, a pulsed infrared reflectance device for measuring skin blush and pallor has been developed and tested on Space Shuttle missions. This device, for which production rights have been transferred to a commercial company, may be useful in hospitals for detecting the onset of shock, nausea, syncope and related illnesses during surgery and recovery and in intensive care units.

41. An ambulatory monitoring system developed for feedback training experiments in space enables continuous recording of up to nine channels of physiological responses for an 18-hour period. Detailed monitoring of systolic and diastolic blood pressure, for example, can enable people to learn to control their blood pressure.

42. An insulin infusion pump, developed in the United States using space technology, is freeing insulin-dependent diabetics from the rigid schedules of insulin injections. A compact package houses a microprocessor, a long-life battery, a reservoir for the insulin and an infusion system delivering the insulin through a syringe. The patient inserts the needle through the skin, usually in the abdomen, and a mini-pump infuses insulin at either a "basal rate" (continuous delivery) or a "bolus rate" (a larger amount of insulin delivered prior to meals or when blood sugar levels rise). The system can be programmed with up to four basal rates for patients whose insulin requirements change during the course of the day. Research has shown that continuous infusion of "short-acting" insulin, rather than multiple daily injections of long-acting insulin, has helped many diabetics achieve better control of blood sugar levels, thereby minimizing the possibility of complications.

43. An instrument to apply magnetic field impulses to the human body, the "Avimp" instrument developed in the USSR through space technology, can be used for physiotherapeutic muscle stimulation as well as for treating such conditions as inflammation, edema and osteochondrosis. The instrument is effective through clothing, gauze, plaster and other non-metallic coverings with thicknesses up to 10 mm. The lightweight instrument has a broader area of application, a greater effective depth and a greater efficiency of operation than standard instruments. It puts less pressure on the skin and can reduce the treatment period by one third.

44. A multi-purpose portable respirator has been developed to permit extended ventilation of the lungs, treatment of atelectasis, active inhalation of medical aerosols and anaesthesia. It can be used in resuscitation procedures and may be a valuable piece of equipment in ambulances. A spacesuit undergarment designed for cooling astronauts on the lunar surface or during extravehicular activity has been adapted and commercially marketed for use by

people working in high-temperature terrestrial environments and for people with body temperature control disorders that would otherwise severely limit their activities.

45. An anti-bacterial agent, Lactobacterin, was developed in the USSR for protection against changes in the intestinal flora of cosmonauts on long-duration space flights. It is resistant to digestive fluids and enzymes, has exceptionally high adhesiveness and is highly antagonistic to disease-producing micro-organisms. Lactobacterin has spin-off applications for the treatment of colitis of various types and disturbances of the bacterial environment resulting from the use of antibiotics, and for disinfection in obstetrical, gynaecological and other medical practices. It does not have harmful side effects and appears safe to use under all conditions.

46. A process designed for the purification of liquids in space applications provides a new method of clearing toxins from blood without harming the blood. The process consists of the application of a coating to toxin-absorbing materials which are then injected into the bloodstream. The coating allows the materials to absorb toxins without damaging the blood cells, deoxygenating the blood or introducing harmful chemicals into the circulatory system. This new process is simpler and cheaper than the other alternatives and does not reduce the effectiveness of the absorbing material. The absorbing materials may be sterilized by any means, since the coating can withstand temperatures up to 250°C without any change in properties.

47. A transportable artificial kidney has been developed for people suffering from diseases of the kidneys or liver or from poisoning, and for people who have had liver transplant operations. A new process for purifying the liquid separated from the blood conserves non-organic substances in the blood. This makes possible a reduction in the volume of the processing solution from 300 litres to 1.5 litres, making the system much lighter and more compact, as well as lengthening the intervals between dialyses. This artificial kidney can be used in both clinics and ambulances and could be further developed into a portable artificial kidney.

48. A medical station used for preliminary examinations at a spacecraft landing-site can also be used in emergencies to provide on-site medical care to victims of accidents or natural disasters. The station includes several inflatable modules, equipped with advanced medical instruments, including those developed for space research. Field tests in northern and desert areas have demonstrated the use of the system under extreme conditions.

49. In the field of dental treatment, a new material for dental braces, called Nitinol, originally developed for aerospace applications, is being used for long-term straightening of the teeth in children. Nitinol is an alloy of nickel and titanium with an ability to return to its original shape after bending. The material allows brace wires to exert a continuous pull on teeth, reducing the frequency of office visits to change or adjust the braces and, in some cases, reducing overall treatment time.

50. A lightweight portable dental kit comprising a miniature drill, upper and lower forceps for tooth extraction, dental-filling material, anaesthetics and other drugs, and other dental tools has been developed in the USSR for use during space flight. On the ground, this kit can be used for dental first aid during field expeditions and for preventive-care examinations of people in isolated areas.

C. Public safety and assistance for the disabled

51. Space technology has been used to develop an improved breathing system for fire fighters based on portable life-support technology developed for human space flight. Its mass is slightly more than 10 kg, about one third less than previous systems, with a reduced volume to improve the mobility of the wearer. Many manufacturers of breathing apparatus are now producing units that incorporate space technology in some form. Use of this equipment has been reported to have reduced injuries related to the use of breathing apparatus by as much as 90 per cent.

52. Lightweight, fire-resistant, heat-protective materials, originally designed for use in space suits or spacecraft components, have been used to produce new fire-fighting suits, from protective headgear to improved footwear, offering maximum protection and greater ease of movement with high heat, impact, cut and penetration resistance. Research on advanced flame-resistant materials to minimize fire hazards in crewed spacecraft has also resulted in new fire-resistant materials for use in seat cushions or, in a harder form, for door, wall, floor or ceiling panels. This safer material, which is now commercially available, has particular applications in aeroplanes, ships, buses and rapid transit cars, where toxic smoke produced from burning materials is often the major cause of fire fatalities. Space technology also contributed to the development of a new type of smokeless wire and cable insulation. Cable assemblies of this type are being supplied to mass transit systems in the United States and other countries.

53. A high-efficiency anti-reflection coating, developed to coat the windows of early Gemini and Apollo crewed spacecraft and currently used on the Space Shuttle, has been applied in commercial anti-glare filters for use on personal computers to ease operators' problems with blurred vision, itching or burning eyes, eye strain, fatigue and headaches. The coating minimizes the reflected brightness at wavelengths to which the human eye is most sensitive and enhances image-to-background contrast, resolution and readability.

54. A new wheelchair has been developed in the United States using computerized structural analysis techniques developed for space applications to provide an optimal design. Aerospace composite materials, lighter but stronger than metals, were used to produce an 11-kg chair with the strength and weight-bearing capability of a 22-kg stainless steel wheelchair. The new wheelchair can be collapsed for car storage and transport.

55. Based on remote control and robot technology developed for space activities, a voice-controlled wheelchair and manipulator have been developed as an aid for paralysed and other severely handicapped persons. The system is based on a voice-command analyser utilizing a microcomputer. The patient initially repeats commands several times into a microphone and the analyser then recognizes those commands in the patient's particular speech pattern. The computer translates commands into electrical signals, which activate motors that move the wheelchair or manipulator. The manipulator can pick up objects, open doors, turn knobs and perform a variety of other functions.

56. Space technology is also being used in a system that offers severely handicapped people an opportunity to drive cars or other vehicles, thereby affording them the mobility to lead more productive lives. The control system, originally developed for a lunar vehicle, uses an aeroplane-like joystick to accelerate, brake and steer with one hand, allowing a vehicle to be driven by someone with no lower limb control and only limited use of the arms. The driver simply moves the joystick forward to accelerate, backward to brake and from side to side for steering, or any combination of these movements. The system can be adapted to an ordinary vehicle.

D. New materials

57. A wide variety of new materials with unique mechanical and chemical properties have been developed for use in space, including composites, ceramics, high-strength and polymer materials, and heat- and corrosion-resistant steels and alloys. Many of these materials are being used in various other fields of human activity. Spin-off applications of these materials in the USSR, for example, are estimated to have generated revenue of 600 million roubles.

58. The wide use of aerospace composite materials such as carbon-carbon, carbon plastics and glass-fibre plastics is due to their high strength, low weight, heat resistance, elasticity and resistance to corrosion. Carbon-carbon composites are being widely used in health care, light industry, the food industry and sports. Special carbon materials can be used for prosthetic implants and artificial tendons, ligaments, eardrums and blood vessels. They are much less likely to cause clotting problems than alternative materials, and their use in medicine can substantially reduce recovery time, avoid follow-up operations and shorten rehabilitation periods.

59. Aerospace polymer composites are used in agriculture and industry to replace stainless steel and for coating various types of cooking vessels, storage tanks and containers for grains and liquids. The use of glass-fibre materials in containers for the storage of highly reactive chemical in liquid and gas form provides longer operating lives and saves large quantities of stainless steel. In the USSR, this spin-off application is estimated to generate revenues of about 400 million roubles a year.

60. Lightweight, high-strength alloys of titanium, tungsten, niobium, molybdenum and tantalum, developed for rocket motors, are being used in aircraft construction, shipbuilding and car manufacture, as well as for the manufacture of cutting equipment. Since these alloys can withstand higher temperatures, they are also used in energy generation and engineering machinery. The wide use of high-strength alloys in industry has been estimated to reduce costs by 25 to 40 per cent.

61. Ceramic materials developed to meet the needs of space activities are coming into wide use in the manufacture of machine tools, textile and printing machinery, cars engines and chemicals. The use of ceramics in machinery for the production of chemical fibres has been found to increase the useful life of such machinery three to four times, its productivity two to three times and the durability of the fibres by 20 to 30 per cent.

62. Foam plastics developed for thermal insulation of liquid hydrogen fuel tanks are now being used as insulating material that can be injected into the interstices and cavities of prefabricated buildings. Foam concrete, which is just as strong as reinforced concrete but with only half the weight, can be used to build such structures as residential buildings, hydraulic engineering installations and industrial and stock-raising facilities.

63. Porous fire-resistant coatings developed for space applications have proved effective for the manufacture of fuel tanks and ship hulls. High-vacuum lubricants, "self-lubricating" construction materials, vacuum sealants and thermal insulation materials, also developed in space programmes, are widely used in energy and engineering industries.

64. Cryogenic technology for handling low-temperature liquids, including liquid oxygen and hydrogen rocket fuels and liquid nitrogen cooling systems, is now being transferred to other fields. Liquid nitrogen is used as a coolant for biological materials including transplant organs and samples for analysis. The technology is also used in materials processing for rapid cooling of materials and for maintaining semiconductors at low temperatures. The experience of the space industry in the manufacture, storage, transportation and use of large volumes of liquid hydrogen may be applicable to the development of safe and environmentally sound energy systems based on hydrogen.

65. Extensive research has been done on coatings for the protection of spacecraft systems from the harsh environment of space. A new class of protective coating materials developed for space use has shown promise in protecting outdoor bronze statues from harsh weather conditions and environmental pollutants, such as acid rain. A formula for a zinc silicate coating, developed to reduce the maintenance cost for the steel frames of launching structures, has been used to protect the Statue of Liberty in New York, Panama Canal structures and the Po Lin Temple in Hong Kong. Other applications include bridges, antennae, ocean-going vessels and offshore oil platforms.

66. Space coatings research has also led to the development of dry film lubricants that offer exceptional wearability and friction resistance for spacecraft components, even in the harsh space environment. Space-proven dry lubricant materials are now routinely used by industry for many applications, such as bearings and rotary sleeves in industrial robots, where repetitive movements require special care to prolong useful life.

67. An advanced honeycomb panel, consisting of a tough plastic skin and an aluminium honeycomb interior to combine light weight and high strength, has been developed in Japan. Because of their high stiffness and high damping efficiency, such panels are now being used as low-frequency vibration boards in high-grade audio speakers.

68. A study of the optimal packaging of space materials and structures in Japan resulted in the discovery of a technique for the efficient packaging and easy deployment of sheet-type space structures such as solar arrays. This technique was used commercially as a procedure for folding maps before it was used in space.

69. In India, a variety of products and processes developed by the space programme, including a polyamide resin for glass and carbon composites, polyamic acid, special lubricants derived from castor oil, precipitated silica from rice husk ash and a vinyl ester resin, have been transferred to industry for commercial production.

E. Industrial processes

70. Space technology for precision casting of titanium and other special metals, including techniques for sealed and thin-wall casting, is now being used in engineering, building construction, transport, medicine and municipal services. Applications include hermetically sealed components for food-processing, plumbing and water-supply systems and instruments of highly durable non-ferrous alloys for the public health sector.

71. Precision-molding techniques developed in space programmes for forming sheets and pipes of various cross-sections are being used to produce a large variety of specialized components for the building industry. These techniques are used in impact welding and in light engineering for the production of trimetallic rolled coatings for the food-processing industry. This advanced technology can conserve a substantial amount of the materials involved.

72. Similarly, advances in precision machining have had widespread spin-off applications. Improving the quality of mechanical components, for example, has substantially extended the useful life of many machines, tools and other equipment. In heavy engineering, for example, new precision-machining techniques have been used for making hydraulic cylinders and valves for pneumatic-hydraulic systems for the shields of tunnelling machines, thereby doubling the speed of tunnelling. In medicine, these technologies are used for manufacturing a large number of different parts for prosthetic devices.

73. In the metal-processing industry, vacuum-plasma technology developed for space propulsion systems has been used for producing high-quality coatings for cutting and stamping tools, increasing their wear resistance substantially. Also, precision finishing of parts for machines, dies, moulds, filters, membranes and metal-cutting tools by electrical-discharge and laser techniques increases the durability of these products and therefore their working lifetime.

74. In the development of space technology, much experience has been gathered in various kinds of welding: welding of large containers, welding in a vacuum and robotic spot welding. This experience is being applied in the oil-and-gas industry for diffusion welding of various types of materials, for example for large fuel tanks. Robot systems are used for welding large-diameter pipelines, concrete reinforcing structures, commercial equipment, car bodies and food containers.

75. Sensors, microprocessors and other electronic systems developed for space activities can be used in the installation of highly automated industrial plant and assembly lines. Space technology developed for the production of compact and highly reliable micro-electronics has been applied to the development of radio and television sets, electronic clocks and other consumer goods. Advances in electronic calculator components and design have led to expanded capabilities, increased speed, lower prices and improved quality for consumer and business calculators.

F. Data processing

76. The requirement in space activities, especially in human space flight, for high reliability and safety in the absence of fully realistic testing has meant an unprecedented reliance on computer analysis and simulations. Space activities have therefore generated a variety of new computer technologies, data processing techniques and computer programs. Many of these technologies have had applications outside the space programmes.

77. Space programmes make extensive use of computer programs in such operations as launch and orbit control, analysis of data from spacecraft, control of precision machinery and project administration and management functions. Much of this software can be used directly for secondary applications with little or no modification, and the cost of adapting the programs for special purposes, when necessary, is often far less than the cost of developing a new program.

78. Computer programs developed for space applications have been especially useful in the field of manufacturing and construction. The NASTRAN computer program developed by NASA for structural analysis of large rockets, for example, has been adapted and modified for thousands of other applications. Computer software developed for analysing the motion of truss-type space structures is being used commercially to ensure that large construction cranes can safely handle loads up to 500 tons in a wide range of applications. This

software has enabled engineers to determine more accurately bending moments, deflections and critical loads for latticed crane booms and has saved many hours in analysis time and construction delays. A program written to analyse the motion of multi-body systems has been adapted and used for the analysis of the motion of complex molecules for the purpose of finding new drugs with specific pharmaceutical properties.

79. Another computer program originally developed in a space programme provides support for the development of expert system and artificial intelligence programs on ordinary computers. The program has already been used in the United States for creating expert systems for the chemical industry, for computer-aided design and for developing legal arguments.

80. A computer program developed to predict heat generation and dissipation under different aerospace conditions is now being used commercially in the United States to design aerodynamic structures for areas on aircraft which are subjected to high thermal loads. Substantial savings on design costs have been realized.

81. The search for extraterrestrial intelligence (SETI) requires very high-speed digital signal analysis on a large number of frequency channels simultaneously. A signal processing system that can analyse 74,000 frequency channels simultaneously and perform billions of operations per second has been developed for this purpose in the United States, and more powerful systems are under development. Researchers are developing new types of very-large-scale integrated computer chips, including a digital signal processing chip for high-speed, high-volume processing, and a content-addressable memory chip for recognizing signal patterns that might indicate intelligence. Many spin-off applications of high-speed, multi-frequency signal processing technology are possible, including high-resolution processing of ultrasound signals for medical diagnosis, seismic analysis for geophysical prospecting and earthquake analysis, and air traffic control.

82. Space activities in India have produced an automatic microfiche camera, a system for recording images on photographic film, a drum scanning digitizer, computer software for designing optical systems and an instrument for testing electronic relays. These systems all have important applications in fields other than space.

83. A "virtual reality" computer video system was developed for aerospace applications to allow a user to interact with either a computer-generated environment or a real environment relayed from remote video cameras. The user wears a helmet which produces a three-dimensional display by means of two small television screens - one for each eye - in the helmet's visor. An advanced version of the system is under development in the United States for the remote control of robotic space systems. The system is being used in the movie industry to enable human actors to interact realistically with animated characters.

G. Environment and energy

84. Long-duration human space flight will require advanced life-support systems with extensive recycling, and research is under way to find processes for removing waste products and regenerating oxygen, pure water and food. A central feature of such systems would be the use of green-plant photosynthesis to produce food, while removing carbon dioxide and regenerating oxygen. This research into recycling systems will help in the development of environmentally protective practices on Earth. One spin-off application of this research has been the use of the water hyacinth for removing pollutants from sewage water, a technique now in use in a number of towns in the United States.

85. In recent years there has been a trend towards highly sealed and insulated homes and office buildings in order to conserve energy, but a secondary consequence has been an increased problem of indoor air pollution. The reduced air circulation often results in a build-up of toxic chemicals from a variety of building components such as wallboard, synthetic fibres, adhesives, cleaning products, insecticides, gas-fired appliances and wood-burning fixtures. The result has been a notable increase in allergic reactions and other illnesses due to toxicity. Recent research into maintaining healthy atmospheres in spacecraft has shown that some plants not only absorb carbon dioxide and generate oxygen but also absorb toxic gases, thereby reducing indoor air pollution. Studies have also shown that combining plant foliage with a bed of activated carbon creates a filtration system with a cleansing capability significantly greater than plants alone. Such air filtration systems are now commercially available in the United States for home and office use.

86. An electrochemical water-quality analyser developed for use in space can be used to measure the purity of drinking water, waste water and water from natural sources in order to protect public health. The device can determine micro-quantities of heavy metals and organic impurities in liquid media by their absorption on a platinum micro-electrode. It is extremely sensitive and requires only 5 to 10 minutes for an analysis.

87. Air quality testing instruments based on space technology have been developed in the USSR and the United States for detecting and measuring hazardous impurities in the air, including acetone, benzene, butanol, xylene, toluene and formaldehyde. The sensitivity and the speed of the instruments are much greater than those of standard gas chromatographs.

88. The extensive use of satellite power systems using solar cells to charge batteries has stimulated work on terrestrial solar power production. Solar power systems are currently used in signalling systems for oilfields, railways and ports. Experimental solar systems are being developed for domestic air-conditioning and heating. Highly efficient nickel-cadmium, silver-cadmium and silver-zinc batteries developed for use in space are also coming into use in many terrestrial applications.

89. Stirling engine technology, which has been studied for use in space, could help in dealing with the problem of automotive emissions. Studies are under way to examine the potential of this technology for such spin-off applications.

H. Agriculture

90. Research into life-support systems for long-duration space flight indicate that plants, including common food crops, have a potential productivity under optimal ecological conditions much greater than their current productivity. With current agricultural methods, approximately one acre of farmland is required to produce sufficient food energy for one person from a single annual harvest. Experimental life-support systems based on wheat production in controlled environments have been able to meet the food energy requirements for one person using as little as 0.002 acres (or 500 people per acre). Crops grown under these conditions have a higher protein content, and yields are reliable. Although some space growth stimulating techniques, such as enriching the carbon dioxide in a closed atmosphere, may not be applicable in open fields, the basic knowledge gained from this applied research will be of great value for agricultural development. The design of small, efficient plant growth chambers may have practical value in urban areas, in regions where the natural growing conditions are not suitable for particular valuable crops and in extreme environments such as the Antarctic and deserts.

91. Another area of life-support research is the conversion of inedible plant material into food products. Wheat, for example, contains 60 to 65 per cent inedible biomass, which may be convertible into food products using micro-organisms and enzymes.

92. A critical factor in greenhouse food and flower production has been the cost of artificial illumination. Research into space life-support systems includes the study of energy-efficient lighting systems, which will have broad applications in other fields. Systems using light-emitting diode arrays are more efficient than other light-generating processes, since all of their light energy is emitted in the spectral regions that best promote plant growth.

93. Space programmes are also studying automation and robotics techniques for growing crop plants in space. These automated methods will be useful for commercial hydroponic farming, which could increase production and reduce costs by increasing the level of automation.

III. PROMOTING AND MANAGING SPIN-OFF APPLICATIONS

94. A number of national and regional space agencies have considered ways to promote spin-off applications of technologies developed through space programmes. Such spin-off applications provide direct economic benefits in the fields that make use of the new technologies and may indirectly benefit

space programmes by increasing support for space activities based on recognition of their wider benefits.

A. United States technology transfer programmes

95. In the United States, NASA has established a Technology Utilization Program, which employs several types of mechanisms to stimulate the transfer of aerospace technology to other sectors of the economy. The Program is managed by the Technology Utilization Division within the NASA Office of Commercial Programs.

96. The Technology Utilization Program involves both technology dissemination and technology application. Technology dissemination requires the identification and gathering of information on aerospace technologies and making this information available to the private sector. Technology application involves the use of NASA technologies in specific projects for public benefit.

97. A key component of the Program is a network of 10 Industrial Applications Centers affiliated with universities and other non-profit institutions across the country. The Centers offer clients access to a national data bank that includes bibliographic information on some 100 million documents of accumulated technical knowledge, along with the Centers' expertise in retrieving information and applying it to clients' needs. The Centers are backed by some 35 Industrial Applications Affiliates, which are state-sponsored business or technical centres that provide access to the NASA technology transfer system.

98. In addition to the Industrial Applications Centers, other mechanisms of NASA's Technology Utilization Program include: Technology Utilization Officers, located at NASA field centres, who serve as regional managers for the Program; a software centre that provides industry and government clients with computer programs applicable to secondary uses; applications engineering projects which address public sector problems through the application of aerospace technology; and publications that inform potential users of technologies available for transfer.

99. In cases where technological developments are seen from the outset as being of interest for both space and non-space activities, the developments may be jointly funded. NASA, for example, entered into a joint agreement with two commercial enterprises to develop an implantable calcium ion sensor. The first prototype was to be delivered to NASA for use in biomedical investigations on space flights, and NASA also retains the right to offer the technology, which could be used as well for sodium, potassium and other ions, to other federal agencies such as the National Institutes of Health. The commercial enterprises will make the technology commercially available to the medical community for rapid and accurate analysis of blood.

100. In order to make government-developed aerospace computer programs widely available, NASA has established a Computer Software Management and Information Center (COSMIC). The Center's library contains more than 1,400 programs for such tasks as structural analysis, design of fluid systems, electronic circuit design, chemical analyses, determination of building energy requirements and a great variety of other functions. COSMIC customers can purchase a program for a fraction of its original cost and obtain a return many times the investment, even when the cost of adapting the program to a new use is included. To assist users in locating applicable software, COSMIC publishes an annual indexed catalogue, available on microfiche, on computer magnetic tape or in hard copy form, of all the programs in the Center's inventory.

101. Another means of providing information on technology developed by NASA that is available for transfer is through publications such as the monthly NASA Tech Briefs, containing reports by NASA contractors, with information on inventions, improvements and innovations developed in the course of contract work. The periodical is published jointly by NASA and Associated Business Publications, a private firm. Users interested in a particular innovation may get more detailed information by requesting a Technical Support Package, available to scientists, engineers, business executives and other qualified technology transfer agents in United States industry or government. NASA also publishes an annual report, Spinoff, providing information on programmes generating new technology, examples of spin-off applications and NASA's spin-off mechanisms.

B. Technology transfer in India

102. India, in pursuing its objective of self-reliance in space technology, has promoted active participation by Indian industry in space projects, in part through the transfer to industry of advanced technologies developed in the government space programme. The Indian Space Research Organization (ISRO) has established a technology transfer programme to promote and support the commercialization of technologies developed in the Indian space programme in both space and other fields. Detailed market surveys and feasibility studies for technology transfers are undertaken regularly and technical specialists from the space programme are available as consultants to industry to assist the transfer. The technology transfer programme has been particularly active in the fields of aviation, electronics, communications, electro-optics, chemicals and pharmaceuticals. While some technologies are transferred to industry specifically for production for the space programme, the industrial transfer is expected to enhance the capabilities of industry in non-space fields as well. 7/

103. As of 1989, 164 technologies had been transferred or were in the process of transfer from ISRO and the National Remote Sensing Agency to industry, generally on the basis of a non-exclusive licence, with an increasing proportion of the technologies being used for non-space applications. A growing number of requests are also being received from abroad for these technologies, and steps are being taken to develop mechanisms for transferring technology overseas, including a standard format for international contracts.

104. In granting non-exclusive licences for commercial spin-off applications, an effort is made to ensure that the number of licensees is commensurate with the market potential of the technology and with the space programme's capacity to support the transfer. Financial arrangements generally include a down payment and royalty payments, with the prices to be determined by the market.

105. Interest Exploration Notes are published with a view to providing details of technologies developed by ISRO and available for transfer. The Notes are disseminated to a wide range of industrial and other high-technology institutions and potential users. Announcements of available technologies are also made in professional journals and newspapers. Demonstrations of products and processes with transfer potential are arranged for industry representatives, usually as part of meetings organized to promote industrial development in specific areas such as communications, image analysis systems and computer applications programmes.

106. ISRO also provides expert consultants to Indian industries and other research-and-development institutions in a wide range of disciplines. Consultants have been provided for applications including meteorological sensors, testing methods for printed circuit boards and high-speed image processing systems.

C. Spin-offs from the Soviet space programme

107. In the past, interest in spin-offs of space technology in the USSR focused on medical and biological results from the human space-flight programme, with the Institute for Medico-Biological Problems of the Ministry of Health as the primary institution concerned with spin-offs. More recently, as the Soviet space programme has increasingly promoted commercial activities through such organizations as Glavcosmos, spin-off applications in other areas have received more attention.

D. Technology transfer in Japan

108. The Japanese space programme, like other space programmes, makes extensive use of national industrial capabilities. While the Japanese space programme has made little effort devoted specifically to studying or promoting spin-off benefits of space technology, the involvement of industry in the space programme tends to promote spin-off applications.

E. Spin-off programme in France

109. In 1986, the Centre national d'études spatiales (CNES), the French space agency, in collaboration with other investors, established the Novespace company for the purpose of promoting spin-off applications of space technology to non-space sectors. Novespace identifies transferable technologies developed by CNES and by the space industry in such fields as electronics,

optics, new materials and medicine and actively promotes their transfer to other sectors. The new technologies may take the form of patents, computer programs, expertise, etc., and are publicized in the quarterly report, Mutations. Novespace works with companies on marketing studies, licensing arrangements and investment. 8/

F. Spin-off assessment in the European Space Agency

110. ESA and its Industrial Policy Committee are working to increase the transfer of space technology to non-space sectors. As noted above (see para. 26), two studies of the secondary economic effects of ESA contracts have been undertaken, including effects of both commercial space activities and non-space activities. In 1989, ESA organized a workshop on spin-offs, including representatives from the space industry and the ESA Industrial Policy Committee, to examine ways to stimulate the transfer of space technology to non-space applications.

111. In order to investigate the quantitative and qualitative aspects of the transfer problem, a pilot transfer exercise is being undertaken to demonstrate to the European space industry the existence of transferable technologies, to determine the level of interest of non-space industries and to identify the industrial sector with the strongest demand for space technology. An inventory of existing structures for the promotion of innovation is being planned, to be used in support of the transfer of specific space technologies to non-space sectors. 9/

IV. CONCLUSION

112. The relationship of space technology to other, often overlapping fields of technology is a complex one, and the spin-off of technological innovation from one field to another is a complex process. This spin-off process has historically taken place without planning or analysis. At present, however, the growing need for more careful analysis, justification and planning of public expenditures on space research and development means that studies of the cost and benefits of space activities, including spin-off benefits, are increasingly important in many countries.

113. While studies of spin-offs are generally undertaken for national purposes, the results of these studies and the results of programmes to promote spin-offs can be valuable to other countries interested in the question of spin-off applications and spin-off benefits. Studies that identify actual or potential spin-off benefits of space activities in one country can be useful for stimulating similar spin-offs in other countries with similar space activities.

114. Furthermore, owing to the difficulties of comprehensively identifying spin-offs, different studies in different countries will undoubtedly find different actual and potential spin-offs. The collective international effort

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will certainly be more comprehensive than any individual national effort at identifying the full range and magnitude of the benefits resulting from space activities.

115. In an international context, the evaluation of the benefits of spin-offs should not be limited to benefits at the national level, as is usually the case with national studies. Spin-off applications in health and medicine, safety, industrial production, data processing and other fields, and the benefits of those applications, will quickly spread to other countries through trade, education, technical assistance or other forms of technology transfer. These processes will result in better goods and services for consumers and promote economic growth throughout the world.

116. International efforts to enable more countries to gain more benefits from the spin-off applications of space technology should probably be focused on improving the exchange of information relating to actual and potential spin-off technologies, applications and benefits.

117. The Committee on the Peaceful Uses of Outer Space could play a useful role in promoting this exchange of information by various means, including consideration of the related agenda item in the Committee, submission by Member States of reports on the subject for general distribution and inclusion of information on the subject in annual reports on national space activities submitted to the Committee and circulated as United Nations documents.

Notes

1/ Official Records of the General Assembly, Forty-fifth Session, Supplement No. 20 (A/45/20), para. 132.

2/ Ibid., para. 139.

3/ Spinoff 1989, National Aeronautics and Space Administration (NASA).

4/ Chapman, Richard L., Loretta C. Lohman and Marily J. Chapman, An Exploration of Benefits from NASA "Spinoff", NASA, 1989.

5/ Etudes sur les effets économiques des dépenses spatiales européennes, European Space Agency (ESA), 1988.

6/ "Spinoffs show large growth in European space patents", Space news, 29 October-4 November 1990.

7/ Government of India, Department of Space, Annual Report 1989-90, Indian Space Research Organization (ISRO), Bangalore, India.

8/ La lettre du CNES, No. 112, 5 October 1987.

9/ ESA Annual Report 1989.

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COMMITTEE ON THE PEACEFUL
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SCIENTIFIC AND TECHNICAL PRESENTATIONS TO THE SCIENTIFIC AND
TECHNICAL SUBCOMMITTEE

Report by the Secretariat

1. During the twenty-eighth session of the Scientific and Technical Subcommittee, held from 19 February to 1 March 1991, the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU) and the International Astronautical Federation (IAF) organized a symposium on the theme "Applications of airborne and satellite remote sensing for prospecting mineral and groundwater resources and for monitoring and managing biological resources, with emphasis on agriculture, taking into particular account the needs of developing countries". The symposium was organized in accordance with the recommendation of the Subcommittee at its twenty-seventh session, in 1990, that the subject be fixed for special attention at the 1991 session and that COSPAR and IAF be invited to arrange a symposium on the topic. The recommendation was subsequently endorsed by the Committee on the Peaceful Uses of Outer Space and by the General Assembly in its resolution 45/72 of 11 December 1990.
2. The symposium was the seventh to be organized by COSPAR and IAF during the annual meetings of the Scientific and Technical Subcommittee, with the topic for each year selected by the Subcommittee at the previous session. The symposium was held in two parts, on 20 and 21 February 1991, following the completion of debate in the afternoon meetings of the Subcommittee during the first week of its session.
3. A special presentation was also organized by COSPAR on "The International Geosphere-Biosphere Programme: the challenge for remote sensing", in response to an invitation from the Subcommittee endorsed by the Committee and the General Assembly. This was the sixth in an annual series of such progress reports to the Scientific and Technical Subcommittee. The presentation was made on 19 February 1991.

4. In addition to these special presentations organized by COSPAR and IAF at the request of the Subcommittee, delegations of Member States provided a number of scientific and technical presentations by specialists in space science and applications relating to various items on the agenda of the Subcommittee. Several international organizations also made special presentations on their scientific and technical activities. These special presentations covered a variety of topics, including the activities planned for International Space Year (ISY), education in space technology and applications, the space environment, space transportation systems, life sciences, astronomy and planetary exploration.

5. The presentations on the subject of remote sensing for mineral prospecting indicated that remote sensing was being used productively for mineral prospecting in many countries. When satellite images first became available, one of the surprising discoveries was the abundance of long linear features that were not visible either from the ground or from aerial photographs. While these features are still not fully understood, it is clear that they are often related to mineral concentrations. Satellite images also reveal subtle colour patterns in soils or vegetation that sometimes indicate deposits of valuable minerals. Multi-spectral sensing and analysis techniques, often using large numbers of narrow spectral bands, are currently being developed to enhance these colour anomalies and study their association with the mineral content of the soil. Research is also being done in the use of infrared scanning to observe the thermal properties of soils and rocks, which are related to their mineral characteristics. Another new remote sensing application under development is the analysis of coastal plumes of suspended sediments as an indicator of underwater tectonic structures.

6. The analysis of linear features on remote sensing imagery has also contributed to groundwater development. As part of its programme for improving village water supplies, India has undertaken a major remote sensing project for mapping areas where groundwater is likely to be accessible. Maps of groundwater potential were prepared, first of drought-prone areas and subsequently of the entire country, and detailed maps indicating prospective well sites were prepared for villages with known water supply problems. These maps have improved the success rate of well digging from 45 per cent to 90 per cent. Remote sensing is also being used to study ways to conserve rainfall, either through direct collection or through groundwater recharge. In Canada, thermal infrared sensing is being used to identify surface and near-surface water sources, which appear as anomalously warm areas at night. In cases of flooding, the all-weather capability of airborne and satellite radar has proved extremely valuable for showing the changing flood conditions and thereby guiding flood relief efforts.

7. Remote sensing has proved very cost-effective for forest mapping and monitoring in many countries. Forest clearing is generally readily visible on either multi-spectral or radar imagery, and thermal infrared scanning is being used for forest fire monitoring. A subject of particular interest recently has been tropical deforestation, especially in the Brazilian Amazon region, and a number of estimates have been made of the rate of deforestation and its

possible contribution to global warming through the greenhouse effect. A recent study of Amazonian deforestation using Landsat images has revealed that the rate is substantially lower than previous estimates, although it is still a matter for concern. There are plans to develop an international world forest watch programme to monitor tropical deforestation as part of international global climate monitoring.

8. Multi-spectral remote sensing imagery is being increasingly used to monitor changing conditions in crops and other plants by means of a "vegetation index" that is calculated from the relative values of different spectral bands. The vegetation index has been demonstrated to be a good indicator of the density of green vegetation under a variety of conditions and is being used operationally for crop production estimates and environmental monitoring. Remote sensing is also being used to study land degradation due to such processes as salinization, waterlogging and erosion and to plan land reclamation.

9. Another recent major development in remote sensing has been the integration of remote sensing data into computerized geographic information systems (GIS). GIS computer programs, which are available for personal computers, are based on a geographical grid in which various types of geographic data, from remote sensing and other sources, can be stored. A GIS for estimating agricultural production, for example, includes data on soils, weather, historical agricultural statistics, cropping intensity and a vegetative index derived from satellite remote sensing. The various data can be printed or displayed as images or maps, as can any combination of different data.

10. Remote sensing will be a major element of the activities planned for International Space Year, to be celebrated in 1992. Most ISY activities are being coordinated by the Space Agency Forum for International Space Year (SAFISY), which includes 28 national and international space agencies and 8 affiliate organizations, including the United Nations Outer Space Affairs Division. SAFISY has established three panels of experts to review and coordinate projects: a Panel on Earth Science and Technology; a Panel on Education and Applications; and a Panel on Space Science. Each project will be led by one agency and will be open to participation by others. The focus of most of the projects will be remote sensing of the environment.

11. The International Geosphere-Biosphere Programme (IGBP) coordinates scientific studies aimed at improving knowledge of the global environment and developing models for predicting global environmental change resulting from either human activities or natural forces. The Programme will consist of core projects studying atmospheric, oceanic, vegetative and land surface processes and their interactions. This global change monitoring requires consistent data over periods of 10 years or more, and for many phenomena such data are not currently available. One of the goals of the Programme is to promote long-term planning of data collection.

12. An educational programme related to both ISY and IGBP is the Global Change Encyclopaedia, a computer-based environmental information system particularly designed for use in schools. The Encyclopaedia will consist of a variety of global environmental data distributed on CD-ROMs together with computer programs for examining and manipulating the data on a personal computer. The system will function like a simple environmental geographic information system, allowing selection of a geographic area, display of images, overlay of different data and enlargement and enhancement of areas and features of interest.

13. An ongoing educational programme is the International Space University, which has since 1987 conducted an annual series of summer courses for graduate-level young professionals from all over the world. The course consists of lectures on all aspects of space activities and work on design projects for new space activities. The International Space University, which has held summer courses in various countries, intends to establish a permanent campus in 1995 offering year-round study.

14. The International Institute for Aerospace Survey and Earth Sciences (ITC), in the Netherlands, offers education in remote sensing to students from developing countries. Originally focusing on air photo interpretation, the Institute has integrated remote sensing applications into its programme as they have developed. The Institute emphasizes the integrated application of remote sensing, air survey and ground survey methods for mapping, resource surveys and environmental monitoring. The Institute cooperates with a number of institutions in developing countries offering similar educational programmes.

15. The problem of space debris has become the subject of increasing concern in recent years, and a number of countries are studying the question. About 7,100 space objects, the great majority of them non-functional, are currently being tracked by radar or optical systems. The tracked objects, however, represent only the larger objects, and estimates of the number of objects that are too small to be tracked but large enough to damage a spacecraft range from about 20,000 to 70,000. Much of this smaller debris is the result of the fragmentation of spacecraft due to either explosions or collisions. Efforts have been made to calculate the distribution of small debris by size and altitude based on known fragmentation events, experimental patterns of fragmentation and the theoretical evolution of debris orbits.

16. While debris in low orbit re-enters the Earth's atmosphere and burns up after some years, debris in higher orbits will remain for centuries or longer. A steady increase in space debris will eventually interfere severely with space activities. The accumulation of debris can be reduced by preventing collisions and explosions and by removing spacecraft from orbit at the end of their functional lives. Non-functional objects could only be removed by complex and costly retrieval operations for which no technology currently exists. One possible concept for a future retrieval satellite would involve the use of a tether to transfer energy from large objects in high orbit, lowering their orbits until they re-enter the Earth's atmosphere.

17. Japan initially acquired a satellite launching capability based on launcher technology of the United States of America, but is now developing an entirely domestic technology. Beginning with the N-I and N-II rockets, Japan has upgraded its capability by increasing the power of the various stages as well as the accuracy of the guidance system. The H-II rocket, currently under development, will be capable of launching a 2-ton payload into geostationary orbit or interplanetary trajectory.

18. Space activities have made major contributions to medicine, both through scientific research during human space flight and through applications of space technology to medicine. Communication satellites, for example, have been used for "tele-medicine", notably in the joint Spacebridge project of the United States and the Union of Soviet Socialist Republics which made United States medical expertise available for victims of an earthquake and a train accident in Armenia. In the United States, remote sensing is being used to identify environmental conditions that support the breeding of disease-bearing insects. Technologies developed for life-support systems for human space flight are also being used on Earth for improving plant growth, recycling waste products and developing new intensive agricultural methods.

19. The last few years have seen the launching of astronomical satellites and planetary probes that will greatly expand scientific knowledge of the solar system and the universe. The Hubble Space Telescope, despite some problems, is returning astronomical data substantially superior to anything available from ground observatories, and the recently launched Gamma Ray Observatory will soon begin its observing programme. Three planetary probes have recently been launched: Magellan is carrying out a systematic and detailed radar mapping of Venus; Galileo has completed the first of two gravitational-assist manoeuvres around the Earth on its way to Jupiter; and Ulysses is heading towards Jupiter for a gravity-assist manoeuvre that will send it out of the plane of the solar system and over the polar regions of the Sun. Future missions to Mars and Saturn and a mission to study comets and asteroids are being planned.

20. The annex to the present report contains a more detailed summary of the scientific and technical presentations during the 1991 session of the Scientific and Technical Subcommittee. Because of the technical character of the material, the annex appears in English only. A list of the presentations and the speakers is contained in the appendix to the annex.

Annex

SUMMARY OF SCIENTIFIC AND TECHNICAL PRESENTATION TO
THE SCIENTIFIC AND TECHNICAL SUBCOMMITTEE AT ITS
TWENTY-EIGHTH SESSION

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I. APPLICATIONS OF REMOTE SENSING FOR MINERAL, WATER,
AND AGRICULTURAL RESOURCES

A. Remote sensing of mineral resources in India, the
United States of America and Canada

1. The acquisition of Earth resources data by remote sensing is a logical extension of existing resource management capabilities, but provides information more quickly and economically. Remote sensing instruments include passive and active sensors and use different spectral bands of visible and infrared light, as well as microwaves. Although remote sensing does not directly solve the resource development problems of developing countries, it has become an invaluable tool for information collection and supplies a wealth of information that reflects the interconnection, diversity and scale of global problems in a way that has never been possible before. Remote sensing maximizes the amount of information and area of coverage at minimum cost and allows decision-makers to address a variety of resource management problems far more rapidly than by conventional survey methods.
2. Most mineral resources are non-renewable. Maintaining the known reserves of these resources at a level that can meet future needs requires the discovery and evaluation of new sources. Airborne and space remote sensing systems are used in four aspects of mineral exploration: (i) structural analysis on a regional scale; (ii) spectral identification of rock types; (iii) location of geobotanical anomalies; and (iv) data integration.
3. Geological, geomorphological and tectonic maps are designed to show features associated with mineralization and to delineate target areas for exploration. While remote sensing cannot entirely replace ground surveys, it does provide information that assists in the recognition and delineation of mineral zones by showing surface indicators and geomorphological features.
4. In India, aerial photography is widely used for delineating target areas for mineral exploration. The delineation of bauxite-capped plateaux in the Eastern Ghats of Andhra Pradesh and Orissa States, an area of mountainous terrain and difficult access, for example, was greatly facilitated by aerial photography.
5. Aerial photography has been used to locate buried deposits of calcareous nodules, known as Kankar, in the alluvial areas of Uttar Pradesh and the desert terrain of Rajasthan by the Geological Survey of India. These were important discoveries in the Indo-Gangetic plain and the Rajasthan desert where hard rocks are not found. On the basis of photographic tone and texture, vegetation types, drainage patterns and geomorphic associations, 28 potential sites of nodular and bedded Kankar were delineated, reducing the target area by a factor of over 700 and giving a success rate of 80 per cent. Similar studies carried out over an area of 3,500 sq km in the Bikaner and Nagaur districts of Rajasthan have led to 103 workable deposits of Kankar with a success rate varying from 77 to 90 per cent.

6. Airborne electronic scanner imagery is being used to locate zones of geothermal energy. Infrared scanning is used to identify surface manifestations such as hot springs, hot spots and oil and gas leaks, and multispectral scanning is used for mapping geological structures and detecting rock types associated with underground heat sources. Thermal infrared images have also been used successfully for rock type discrimination and for mapping lineaments.
7. Satellite data, particularly from Landsat, have been used in mineral exploration in two ways: first, for identifying features directly related to mineralization, such as alteration zones, specific host rocks or characteristic mineral associations; and secondly, for delineating features favourable for mineralization, such as folds, faults and fractures.
8. The study of lineaments has assumed great significance because of their correlation with known mineral deposits all over the world. Potential ore bodies occur along or in close proximity to major lineaments representing fracture zones and often at the intersection of two or more lineaments in the mineralized area. In the Khetri and Singhbhum areas, the intersection points of different sets of lineaments are thought to be favourable zones for mineral deposits. The limits and extent of mineral belts can also be assessed through studies of lineaments and the identification of rocks and minerals, as has been done in the Singhbhum Shear Zone in Orissa using Landsat data.
9. In addition to mapping structural features such as lineaments, satellite data have been used to locate anomalous tonal areas directly related to mineral deposits, although this application is sometimes limited by spatial resolution. In the Eastern Ghat terrain of Orissa State, bauxitic lateritic plateaux could be identified through visual interpretation of Landsat data because such plateaux occur as flat surfaces on top of hills and ridges and have a distinct tone on the images.
10. The delineation of anomalous tonal areas is particularly useful for locating sulphide ore deposits and uranium mineralization since these deposits form distinctive alteration zones at the surface. Image enhancement techniques such as band ratioing have been developed to enhance or distinguish these altered zones. These colour composite images of band ratios highlight the differences in spectral reflectance which are related to rock type, thereby facilitating the delineation of altered zones for mineral exploration.
11. Even with certain constraints, particularly those of spatial resolution, satellite remote sensing techniques have proved their value in mineral exploration and other geological applications. Satellite remote sensing has therefore become an important tool for preparing regional geological and geomorphological maps of areas not previously mapped, for updating and revising existing maps, for correlating geological features and structures over large areas and for delineating target areas in mineralized belts for detailed study by airborne and ground surveys.

12. With the goal of making mineral prospecting as efficient as possible, the Geological Survey of India and the Indian Space Research Organization have started a collaborative effort called "Project Vasundhara", including the following elements:

- (a) Identification and mapping of regional litho-stratigraphic, structural and geo-environmental indicators of mineral localization;
- (b) Determination of statistical indicators of mineral probabilities;
- (c) Development of computer overlay techniques and a geographic information system (GIS) database to display thematic data;
- (d) Development of methodologies for multi-level, multi-theme data integration;
- (e) Delineation of target areas for mineral search.

13. The Project covers the Indian peninsular shield, south of latitude 16 N, an area of about 400,000 sq km. The work carried out so far includes preparation of the following:

- (a) Geoscientific maps based on IRS-1A and Landsat Thematic Mapper (TM) imagery and aerial geophysical data;
- (b) Synoptic geological and geophysical maps at a scale of 1:500,000 combining remote sensing data with existing geological and geophysical maps;
- (c) A detailed inventory of mineral occurrences in the project area in a standardized format;
- (d) Digital analysis of seven areas and field surveys;
- (e) Development of an operational GIS with a digital cartographic database with a 250 m grid cell.

14. Digital analysis of data from one study area in Andhra Pradesh has led to the location of a lead-zinc deposit, and detailed prospecting by mapping and drilling is in progress. Structural analysis has identified some major lineaments as indicators of mineral potential and crustal evolution. The GIS package developed in this project includes a Mineral Information System database with 37 types of information, which can be conveniently retrieved.

15. Landsat data have now been used for 10 years in energy and mineral exploration. Many larger petroleum companies have a world-wide database of Landsat images, and interpretation of these data is now a routine procedure for identifying exploration targets. Both mineral and energy exploration companies have found that Landsat's large-area coverage can be valuable for delineating structural features and identifying minerals and anomalous vegetation patterns that are indicators of mineralization and potential areas of hydrocarbon accumulations.

16. When Landsat data appeared, geoscientists discovered linear features that extended to tens, if not hundreds, of kilometres. The extent and abundance of these long linear features had not been previously recognized, and no geological models existed that could explain them satisfactorily. Although the geological significance of these landscape features is still not completely understood, many of them have now been recognized as the surface expression of fracture zones in the Earth's crust that have been active for long periods of geological time. Systematic mapping of these linear features from Landsat data is now accepted practice when used with geophysical or subsurface data to define exploration targets.

17. For the past 15 years, the United States Geological Survey (USGS) and the Jet Propulsion Laboratory (JPL) of the California Institute of Technology (United States) have cooperatively investigated the applicability of Landsat data to geological mapping for mineral resource investigations. This research has shown that iron oxide coatings can be detected on rocks and soils using computer processing of Landsat Multispectral Scanner (MSS) data. USGS and industry geologists now routinely use iron oxide abundance maps, derived from Landsat data, to guide their field investigations.

18. Research by USGS and JPL scientists in 1975 had shown that if another infrared band was added to the new TM sensor on Landsat 4 it would be possible to discriminate not only iron oxides but clays as well. In 1977, the United States National Aeronautics and Space Administration (NASA) decided to include the additional channel on the TM sensor. With a view to the further study of the requirements of the geological community, NASA offered to acquire data using aircraft and satellites over eight industry test sites in the United States selected by the Geosat Committee of industry geologists.

19. In the above project, which has now been completed, three sites were evaluated in Arizona to determine the applicability of remote sensing for targeting porphyry copper mineralization, two sites in Utah and Wyoming to study uranium deposits and three sites in Texas, West Virginia, and Wyoming for oil and gas deposits. The most important conclusion of the study was that increased spectral resolution (i.e., narrower wavelength bands) was of much greater importance than increased spatial resolution.

20. In many areas of the world, vegetation obscures rock and soil materials, and remote sensing techniques must use variations in vegetation patterns as indicators of the underlying geologic materials. In some areas, such as Australia, rock types are not well exposed, and even outcrops do not produce characteristic weathering patterns. However, plant species are selective in associating with particular rock materials, and geological mapping can be quite accurate even without observing the rock materials themselves. With repetitive Landsat data, the optimal times of year for "geobotanical" mapping can be selected and the data can be computer-enhanced to bring out subtle variations in plant cover.

21. Anomalous concentrations of elements may cause vegetation to undergo stress and stunting, and these areas can be readily identified from Landsat

data. The USGS and the United States Steel Corporation studied an area in Indonesia to determine whether sites with nickel-laterite crusts could be identified. The study demonstrated that known crusts could be detected and mapped on the basis of vegetation patterns, and that the analysis could be extended to other areas to delineate potential new sites for exploration. The areas analysed in the study were covered with dense, triple-canopy vegetation.

22. Analysis of the data from the experimental Shuttle Multispectral Infrared Radiometer demonstrated that direct mineralogic identification of carbonates and specific clay minerals was possible using narrow (20 nanometres) wavelength band measurements from Earth orbit. Analysis of images of Baja California indicated that clay and iron oxides were abundant, and subsequent fieldwork documented that a zone of hydrothermal alteration had been detected. When the Mexican Government analysed mineral samples, they confirmed that a previously unknown deposit of silver and molybdenum had been discovered.

23. To prepare the scientific community for analysing data from the future Shuttle Imaging Spectrometer Experiment (SISEX), NASA is supporting investigators through an airborne imaging spectrometer programme. Ultimately, a High Resolution Imaging Spectrometer (HIRIS) will be flown on the polar-orbiting platform where it is to be complemented by the Moderate Resolution Imaging Spectrometer (MODIS). The 35 spectral bands of the instrument (with a spatial resolution of 0.5 km) will include those necessary for discriminating soils from vegetation, assessing vegetation properties and observing suspended sediments, atmospheric effects of solar radiation, cloud altitudes, snow/cloud discrimination, cloud and surface temperatures and stratospheric aerosols.

24. Thermal infrared mapping also shows great promise for geological applications. When thermal mappers were first made available to geologists, research indicated that the manner in which geological materials warmed up during the day and cooled down at night was related to the physical properties of the materials. These properties, including heat capacity, density and thermal conductivity, combine to determine the thermal inertia of the material. Images indicating thermal inertia have been used to locate faults in unconsolidated alluvium, to map structures in areas having thin alluvial cover and to differentiate dolomitic rocks from limestones.

25. Recently, NASA developed a multiband thermal mapper, the Thermal Infrared Imaging Spectrometer (TIMS), which it has been flying over sites throughout the United States. TIMS data collected over the state of Nevada have demonstrated the ability to map abundances of iron oxides and clay minerals and to differentiate carbonates and sulfates from these minerals. When combined with the ability to evaluate silicon-oxygen bonding and free-silica abundance, TIMS data represent a technological breakthrough for global geological investigations. NASA has therefore proposed to develop a Shuttle TIMS, and plans are under way to add a multiband thermal capability to the HIRIS instrument planned for the late 1990s. Plans are also under way to include four thermal bands on Landsat 7, scheduled for 1996.

26. The Shuttle Imaging Radar (SIR) has provided remote sensing image data not previously available to geoscientists. During experiments with SIR-A in 1981, it actually penetrated the dry sand cover of the Sahara desert and detected bedrock that in field verification work was determined to be more than 3 m below the surface. The radar images, using a wavelength of 23 cm, revealed previously unknown buried valleys, geologic structures and possible Stone Age archaeological sites. Because the radar data are sensitive to variations in roughness and soil moisture and are independent of solar illumination, they provide information not available from Landsat data.

27. The second version of this radar instrument, SIR-B, was flown in 1984 in a higher inclination orbit, and data were acquired at multiple incidence angles over diverse global topography. The new SIR-C system, scheduled for flight in 1991, will use three wavelengths, 3 cm, 7 cm and 23 cm, different polarization patterns and a resolution of 20 to 50 m. Free-flying single-frequency imaging radar systems with similar characteristics are to be flown in the near future on the European Remote Sensing Satellite ERS-1 and the Japanese JERS-1. Canada is preparing its Radarsat for launch in 1994.

28. Multi-frequency, four-polarization airborne radar systems have demonstrated great potential for expanding the application of radar data to a wide variety of Earth resource problems. Multi-frequency data can be used to evaluate variations in surface roughness and dielectric constant, two parameters that are difficult to separate with single-frequency radar. At present, the most important applications appear to be analysis of vegetation and soil moisture, although 7-cm and 23-cm, and perhaps 70-cm radar could be very useful in discriminating geological units on the basis of their roughness. Although most natural surfaces will appear smooth to 70-cm radar, that wavelength could have great potential for detection of bedrock below dry, unconsolidated alluvium.

29. Airborne remote sensing methods developed in Canada are regularly used for mineral and hydrocarbon exploration, both in Canada and internationally. An airborne synthetic aperture radar (SAR), for example, was used by an oil and gas exploration company for a survey of a virtually unexplored, cloud-covered region of Papua New Guinea, where lack of infrastructure made ground surveys very difficult and a thick limestone layer over the potential hydrocarbon reserves made use of traditional methods such as seismic data acquisition ineffective. From the interpretation of the SAR data, which cost about \$200,000, the company located a reserve worth approximately \$2 billion. In addition to radar systems, multichannel imaging and scanning systems have been used successfully for geobotanical exploration surveys, and a laser fluorosensor has provided both profile plots and colour-contour maps of surface oil concentration in offshore areas. All of these data can be used in conjunction with airborne geophysical and seismic data to provide even more effective exploration tools.

**B. Space photography and geological studies in the
Union of Soviet Socialist Republics**

30. Over the past decade, the Soviet Union has gained considerable experience in the use of space photography for studying natural resources and the environment. A large volume of high-quality photographs in different spectral bands has been obtained, mainly from automatic satellites of the Cosmos series. The size of the original negatives is 30 x 30 cm, which makes it possible to cover an area approximately 60 x 60 km with a resolution of about 5 m, and up to 3 m for high-contrast objects.

31. A special method has been developed for printing colour photographs from negatives of different spectral bands using filters to obtain near natural colours. When necessary, geometrically corrected photographs and digital photomaps are prepared, ensuring a high degree of accuracy and conformity to a desired map projection. A wide selection of photomaps at scales ranging from 1:1,000,000 to 1:25,000 are produced in conformity with standard map sheets. This material is useful for compilation of thematic maps which reflect the current state and dynamics of land, water and vegetation resources.

32. To obtain reliable and complete cartographic information, several unique remote sensing technologies have been developed in the Soviet Union. In one procedure, called "precision space survey", selected targets are surveyed by a high-resolution sensor whose orientation perpendicular to the satellite path can be varied. By changing the orientation of the sensor, it is possible to observe more targets of interest during a single orbit and to observe a particular target from several orbits. The probability of clear observations within a given time period can thus be increased substantially, and repetitive surveys and observation of short-lived processes are possible.

33. In 1987-1988, a pilot precision survey was carried out by the Cosmos-1939 spacecraft. For the experiment, 42 targets were selected and 22 orbits were reserved for their observation. In spite of bad weather conditions, more than half of the targets were observed under cloud-free conditions, and some were observed several times. The pilot survey demonstrated the usefulness of the technique for environmental monitoring.

34. Another innovative technique developed in the Soviet Union is the location of tectonic structures on the continental shelf based on the observations of plumes of suspended sediments, which are normally considered an obstacle hampering observation of the sea floor. An analysis of particle-size distribution in sea-floor sediments and in suspended sediments revealed the high correlation between them. A computer analysis of plume density on the image and its correlation with measurements of particle distributions at several surface points is used to generate a map of sea-floor sediments which is subsequently analysed in conjunction with other information such as shelf topography. The resulting map reveals recent tectonic structures, including local uplifts which may be indicators of deeper oil and gas deposits.

35. This method has been tested in the Caspian, Azov and Black seas, at depths of several metres, several tens of metres, and up to 100 metres respectively. In all cases, the results matched the data obtained from marine seismic survey and drilling to within 25 per cent. Furthermore, all structures containing known oil and gas fields were revealed and the new maps were not only more detailed than those compiled by conventional methods but were almost 10 times cheaper.

36. Multi-spectral images have also been used for identification of oil- and gas-bearing regions on land. A method based on correlating strained geological zones with regions of greater diffusion of hydrocarbons and associated fluids was tested in more than 100 oil and gas fields under different geological and topographical conditions. Specially processed satellite imagery clearly revealed over 90 of the fields through their characteristic spectral anomalies. This method of remote sensing prospecting also proved to be rapid, efficient and of low cost.

37. Space and airborne imagery has considerably improved the efficiency of search for kimberlite pipes, where diamonds may be found, especially in cases where the more conventional airborne magnetic surveys are not effective. A number of indicators of kimberlite pipes have been found in satellite images. Ground magnetic surveys and test drilling carried out in identified areas in Siberia resulted in the discovery of kimberlite pipes under sedimentary cover. Tin deposits in the Far Eastern region of the Soviet Union have been studied using similar remote sensing methods.

C. Remote sensing of water resources in Canada and India

38. In Canada, airborne remote sensing is routinely used for water resources management. Techniques used include thermal infrared scanning of groundwater sources at night, when water appears warm compared to background features, and the use of synthetic aperture radar for flood mapping through cloud cover. Radar mapping of floods provides a near-real-time assessment of the extent of flooding, and, in combination with a geographic information system (GIS), can provide an accurate map for use by disaster relief agencies, insurance companies and other agencies which need to respond quickly.

39. Coastal monitoring of phytoplankton or chlorophyll concentrations, pollutants and other features is routinely carried out using Canadian airborne remote sensing systems. The "pushbroom" multi-band (288 bands) imager and the high-resolution pushbroom scanner are used for monitoring phytoplankton, which can be toxic for fish farms and shellfish areas, for assessing fish stocks and setting quotas, for harbour management, including locating dredged channels and submerged vegetation, and for observing water quality factors such as dissolved organic carbon, suspended solids and chlorophyll concentrations. These remote sensing techniques are used for both environmental assessment and regulation enforcement.

40. The very-high-resolution multi-channel scanner MEIS has been used for monitoring beach cleanup in Alaska after the Exxon oil spill in 1989, and a thermal scanner has been used for monitoring the location, intensity and dispersion of thermal plumes in water bodies. Hydrographic mapping can be done using both the Larsen lidar airborne scanner, which can penetrate to depths of 35 m or more, and the high-spatial-resolution scanner FLI for shallow water. The Larsen lidar is used routinely in the preparation of nautical charts for the Canadian Government.

41. In India, 46 per cent of the population lives in small villages. It was estimated in 1986 that 39 per cent of those villages have either no water supply, an inadequate supply or only non-potable water. The problem has become worse since then. During the 1986 drought, the Indian National Remote Sensing Agency and the Space Applications Centre prepared 1:250,000 scale maps showing prospective groundwater zones in four drought-affected states - Maharashtra, Karnataka, Gujarat and Rajasthan.

42. Based on the success of well digging using these experimental maps, the National Drinking Water Technology Mission accepted remote sensing as the starting-point for scientific village water development. Hydro-geomorphological maps at a 1:250,000 scale were prepared for the entire country and an atlas was published. The remote sensing technique was further refined to identify areas of high porosity along streamlets within 1.5 km of villages with water supply problems, and the sites were marked on 1:50,000 scale topographical maps so that concerned states could use the maps effectively at the village level. The success rate in drilling wells where remote sensing was used has been 90 per cent or better in some states, compared with 45 per cent using conventional techniques.

43. Overexploitation of groundwater resources can also be a problem. Remote sensing is being used to study groundwater replenishment and to determine sites where rainwater runoff could be channelled to natural depressions or low areas. Such water impounding structures are being suggested in drought-prone areas of Rajasthan State.

D. Remote sensing for forest management in Brazil, Canada and India

44. Forests are important for protecting the environment and for the development and sustenance of forest-based industries. The effective management of forest resources requires: (1) classification and mapping of forest types; (2) mapping of cleared areas or areas damaged by fire or disease; and (3) evaluation of production potential.

45. Using Landsat MSS data for the 1972-1975 and 1980-1982 periods, the Indian National Remote Sensing Agency (NRSA) compiled vegetation maps at a 1:1 million scale for all of India. A similar study was conducted by the Forest Survey of India for the years 1980-1983. These studies revealed that only 19 per cent of the country was forested and only 11 per cent was covered

by closed forest. The remaining forest area comprised open forests (8 per cent) and mangroves (0.1 per cent).

46. The Forest Survey of India has a programme for the biennial monitoring of vegetation cover for the country. Techniques have been developed at the Space Applications Centre for classifying forest type, estimating density and monitoring afforestation and deforestation. These techniques, using multi-date imagery, have been demonstrated in Karnataka and Madhya Pradesh. Remote sensing has also been used to identify agricultural encroachments into forest areas over the last 15 years in the North Dhule area of Maharashtra. Forest mapping for these purposes at a 1:50,000 scale has been tested by the state forest departments and has shown better than 90 per cent accuracy.

47. In areas of the world with persistent cloud cover, synthetic aperture radar (SAR) has been used in place of aerial photography for forest inventory. A forest survey undertaken in South America has demonstrated the use of high-resolution SAR data for preparing forest management plans for selective timber extraction and processing. Mapping of the physiography, land use and forest cover type was completed in one fifth the time that it would have taken using aerial photography at a similar scale. A multi-band digital imaging system was also used for the identification of forest species based on spectral analysis.

48. Forest depletion occurs through fire, logging, insects, disease and other means. Thermal infrared scanning has been used in Canada for years to map fires in real time for fire crews and for clean-up of "hot spots" following a major fire. Data from the MEIS high-resolution multi-channel digital scanner have provided very accurate maps of burnt areas, such as those caused by the massive fire in Yellowstone National Park in the United States in 1988. Clear cutting, which is the usual logging practice in single-species stands, can be mapped very accurately using airborne or satellite scanners or radar systems.

49. Selective logging, the usual practice in mixed tropical forests, can also be evaluated using SAR data, as has been demonstrated in South-East Asia. SAR data were used to map three levels of logging activity: untouched, logged over 60 cm diameter, and logged over 40 cm diameter - in peat-swamp forest, as well as to identify the rail and road networks used for the logging activity. Assessments of timber growth and forest productivity must take into account insect damage, which can be identified by multi-spectral analysis.

50. Forest plantations, commonly found in the tropics, can be monitored using several types of remote sensing data. For example, SAR data have been used to monitor different stages of growth of eucalyptus in the Congo. Rubber, oil palm, coconut and other plantation types have also been mapped using SAR. For general forest management purposes, including planning of harvesting and restocking, SAR has been used in South-East Asia to provide information on drainage, land use, infrastructure, settlements and cover types.

51. There is growing concern over tropical deforestation, but estimates of the deforestation rate in the Brazilian Amazon region over the last few years

have varied by a factor of four. More reliable estimates are needed to assess deforestation's contribution to global changes such as greenhouse warming and loss of bio-diversity. In a recent study, 222 Landsat Thematic Mapper images covering all of the forested portion of the Brazilian Amazon region at a scale of 1:250,000 were interpreted using conventional photo-interpretation techniques. The measured deforested area as of August 1989 amounted to about 400,000 sq km. Monitoring of deforestation is facilitated by the fact that forestation clearing takes place in the dry season when clear satellite images are most easily acquired.

52. After re-analysis of data from 1978, the average rate of clearing over the period from 1978 to 1989 was found to be about 21,000 sq km per year. This average rate, of course, does not imply that the pace of deforestation was constant over the period. Other Brazilian data for the intermediate years suggest that the rate increased through about 1987, after which it tapered off. The highest concentrations of deforested areas are observed along the roads.

53. This observed deforestation rate of 21,000 sq km per year conflicts sharply with rates that have been used in several recent publications on deforestation and its impacts. The World Resources Institute (WRI) report for 1990-1991 gives a figure of 80,000 sq km per year for the 1980s, and another important study, by Norman Myers, gives 50,000 sq km per year as the rate as of 1988. Both estimates are based on calculations of the burning area derived from the number of fires estimated with the thermal infrared band of the Advanced Very High Resolution Radiometer on the United States National Oceanographic and Atmospheric Administration (NOAA) NOAA-9 meteorological satellite.

54. The Landsat-based estimates seem to represent the most reliable values at present for the forest clearing rate in Brazilian Amazonia. Although the rate seems lower than previously reported, it is none the less high. Among other impacts, Amazonian and other deforestation makes a significant contribution to the global greenhouse effect. According to the Brazilian Institute for Space Research (INPE), it is very important to have a permanent monitoring programme using satellite imagery, particularly over areas with high deforestation rates, as well as over national parks, Indian reserves, mineral exploration areas and around reservoirs.

55. For this purpose, a World Forest Watch (WFW) project is being planned in conjunction with International Space Year. The project is coordinated by INPE and the Joint Research Centre of the European Commission, and several space and research organisations world wide are participating. The project strategy includes global forest monitoring, using the NOAA-AVHRR, and a regional forest monitoring component using Landsat and SPOT data. Global monitoring will cover West Africa, Central Africa, South America, South Asia and South-East Asia, while regional monitoring will include projects covering the Amazonian forests in Bolivia, Peru, Colombia and Venezuela. The first results of the WFW project will be presented in May 1992 during the World Forest Watch Conference in Brazil.

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E. Remote sensing for agricultural planning in India, Canada and the United States

56. Accurate and timely crop forecasting is an essential element in strengthening a country's food security. Periodic estimates during the growing season of crop area and yield and forecasts of growing conditions can be used in planning supplies of pesticides, fertilizers and other inputs. Pre-harvest estimates of crop production can be used by decision-makers in planning the procurement, storage, distribution, pricing and transportation of essential agricultural products.

57. Remote sensing can be used to provide new information and to improve existing information for the agriculture sector. Recent changes in agricultural practices, including irrigation, fertilization, high-yielding varieties and new farming techniques, while increasing production on a short-term basis, can also result in unwanted changes, in such areas as soil salinity, crop pests and crop diseases, which need to be carefully controlled to ensure long-term benefits. Sustaining the green revolution will require monitoring of harmful changes, provision of information and assistance to farmers and corrective management strategies. Timely information is of great value, especially in agricultural disaster management, so that relief action can be taken to minimize economic losses and prevent human suffering.

58. Experience in India with airborne multi-spectral remote sensing shows that, with adequate ground truth, specific crops may be identified and their growth stage assessed. Landsat data have been used for wheat acreage estimation in Haryana, Punjab and parts of Western Uttar Pradesh and Rajasthan. Experiments in acreage estimation of paddy, sorghum and groundnut were conducted in Tamil Nadu, Orissa, Maharashtra and Gujarat States using Landsat MSS and Indian Remote Sensing Satellite (IRS-1A) data. The relationship between a spectral index and crop yield has been established for wheat in Haryana and Punjab States and for rice in Orissa State. IRS-1A data was used to forecast wheat yield during the 1988-1989 season in Haryana State. IRS-1A data were also used for estimating mulberry acreage and for cotton crop condition assessment.

59. Drought continues to be a major factor of uncertainty in Indian agriculture in spite of the technological advances since independence. While drought-proofing strategies have been taken up in India and are showing encouraging results, further work is necessary. India has developed a national/regional system for assessment and monitoring of agricultural drought using a satellite-based vegetation index to provide periodic information on the severity level and persistence of drought conditions. This information is now being used by resource managers in allocating scarce resources to areas where and when they are most needed.

60. The use of aerial photography for soil mapping has accelerated since the 1960s, overcoming some of the limitations of conventional ground surveys. More recently, multi-spectral satellite data have enabled soil scientists to map large areas on a repetitive basis and to monitor degraded lands. At the

National Remote Sensing Agency in Hyderabad, Landsat MSS data have been extensively used for soil mapping and for mapping and monitoring degraded lands. MSS data have been used for mapping at a 1:250,000 scale, while Landsat-TM data can be used at a 1:50,000 scale, allowing more detailed soil mapping.

61. Soil mapping studies in Karnataka and Orissa have demonstrated that IRS-1A data from the Linear Imaging Self-Scanning Sensors (LISS) with a spatial resolution of 35 or 70 m are as effective as Landsat MSS and TM data for characterizing soil boundaries at a 1:250,000 scale. In addition, these data have been extremely useful in delineating degraded lands such as salt-affected lands, waterlogged areas and eroded lands as well as areas of shifting cultivation (jhumlands). A separate study showed that 16 per cent of India is wasteland. Almost half of this land could, with some effort, be reclaimed for agricultural production.

62. Experience in Uttar Pradesh indicated that LISS images at a 1:250,000 scale could help delineate saline, sodic and saline-sodic soils. Optical enlargement of the images to a 1:50,000 scale enabled further differentiation of sodic soils into moderately sodic soils and strongly sodic soils, which is very important for planning reclamation programmes at the district level. Four classes of soil erosion intensity, namely, none to slight, moderate, severe, and very severe, could be characterized at a 1:250,000 scale.

63. Recently, Canada has developed a number of relatively low-cost and portable airborne digital remote sensing systems which can be used for agricultural resource management, including crop inventory, crop forecasting and monitoring of soil degradation. This information can be used by marketing agencies, agricultural statistics agencies, the agricultural industry, agricultural insurance groups and others. While satellite data, particularly NOAA AVHRR data, have been used extensively for monitoring "greenness" on a regional scale as an input to crop forecasting models, airborne remote sensing is used in Canada to provide detailed spectral and spatial information in areas of particular concern, such as areas of highly specialized or high-value crops and areas of drought or other damage.

64. AVHRR data are used for monitoring grain crops on the Canadian prairies, and Landsat TM data are used for surveying beans in the Atlantic region. Aerial photography is used for gathering more detailed information, for example, for drought evaluation in Ontario. Thermal infrared scanning has been used to provide near-real-time information on frost pockets and crop damage, which is particularly valuable for orchards and other high-value crops.

65. Research in Canada using airborne radar, in preparation for the Radarsat satellite to be launched in 1994, has shown that crop types, soil moisture and other agricultural parameters can be evaluated using radar images. Radar data have also been used in tropical areas for monitoring cocoa, rice, bananas, tapioca and other crops.

66. The integration of airborne remote sensing data into geographic information systems (GIS) is becoming an important technique. A database including field boundaries, crop types, soil types, drainage systems and previous crops provides a versatile tool for crop inventories and crop condition monitoring. A project in Thailand has demonstrated the classification of crop types from Landsat TM data, input of the information into a GIS and extraction of information on crop location and area for use in agricultural economics studies.

67. Soil degradation is a matter of concern worldwide and is related to such processes as wind and water erosion, moisture surplus or deficiency and salinization. The spectral detail, geometric accuracy and stereo capability provided by the MEIS high-resolution multi-spectral scanner have been used to map erosion susceptibility based on micro-topography and soil organic matter content. Thermal infrared scanning has been used to identify areas of waterlogging leading to crop loss and salinization, as illustrated by the detection of an aqueduct leak in California that resulted in crop losses.

68. In the United States, operational satellite remote sensing for monitoring agricultural production around the world is carried out by the Foreign Agricultural Service (FAS) of the United States Department of Agriculture (USDA). The Service provides crop condition assessments and production estimates on a wide range of commodities through the use of satellite remote sensing data, meteorological data, national statistical data, agricultural reports and other agricultural information.

69. The operation provides routine as well as special reports on such subjects as food and feed grains, oilseeds and other industrial crops, winter kill in small grains, deforestation, water impoundments, plant diseases, and moisture stress. Three major data sets are used: Landsat and NOAA satellite data; meteorological data on rainfall and temperature; and ancillary material such as soil maps, historical statistical data, crop model results, and current situation reports from the USDA foreign agricultural attaché service. A computer database, using base maps divided into 45 x 45 km grid cells, contains information on soils, weather, historical agricultural statistics, cropping intensity, model results and a vegetative index derived from remote sensing data. Information can be extracted and displayed on graphic terminals or printed as hard copy. The database information is also used in the interpretation of the remote sensing data. The vegetative index indicates the "greenness" of the crop and is used to compare crop conditions and growth during and between years. The index data are permanently stored in the database for reference when succeeding data are analysed.

70. Most common crop estimates are based on estimated increases or decreases with respect to a defined standard, based on estimates of variation in crop area and year in relation to the standard. When a significant change in cropping pattern is observed, for example due to cultivation of new land, then information on soil types and climatic conditions is used to estimate the additional production of the new crops. If a substantial anomaly is observed that cannot be accounted for by the information in the database, a field trip

may be necessary to determine the cause. The system requires a thorough knowledge of local agricultural conditions and practices in each area. The value of the remote sensing data depends on its effective integration into an information system using data from a variety of sources.

II. ACTIVITIES RELATED TO INTERNATIONAL SPACE YEAR 1992

A. ISY activities coordinated by SAFISY

71. International Space Year, which will be celebrated in 1992, is a world-wide initiative to enhance international collaboration in space activities and to increase public awareness of the benefits of space activities. The main theme of the Year is "Mission to Planet Earth", and there will be a particular focus on the use of space technology for studying and monitoring our planet's environment.

72. In addition to remote sensing of the Earth's surface by satellite and the further development of methods of applying satellite data to environmental protection, ISY activities will include the study of the interaction of the Earth's atmosphere with solar activity, other studies of the solar system, microgravity studies and life science research in space.

73. A wide variety of ISY activities is being organized and coordinated by the Space Agency Forum on International Space Year (SAFISY). The Forum consists at present of 28 member agencies and 8 affiliates. The United Nations is represented through the affiliate memberships of its Outer Space Affairs Division and the World Meteorological Organization (WMO), with the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) as prospective affiliates. Two national associations have been created to complement ISY scientific and applications activities with public relations activities. These are the United States ISY Association in Washington and the European ISY Association (EURISY) in Paris. There is also an active SAFISY secretariat at the National Space Development Agency (NASDA) of Japan.

74. SAFISY activities are undertaken by interested members and affiliates and are funded directly by the participants. Each project is led by one or two members with established programmes in the field, with other members using their resources to contribute to the project. SAFISY is supported by three panels of experts: on earth science and technology; on education and applications; and on space science.

75. The Panel of Experts on Earth Science and Technology has agreed on 12 projects suggested by international experts which have been grouped into two categories. The first group includes "Space data for global change" and "Global Information System tests" projects. These projects address the most important problems of global environmental change, including ocean variability and climate, polar ice extent, polar stratospheric ozone and world forest monitoring. The second group comprises "Global change outreach" projects,

which will provide the public and political decision-makers with information on space and the global environment.

76. The Panel of Experts on Education and Applications has reviewed a total of 39 proposed projects under two general themes. Under the theme "Training in remote sensing applications", which is to be under the general direction of the French space agency CNES, seven projects have been approved, most of which are linked to ongoing bilateral or multilateral activities in South-East Asia, the Amazon region, semi-arid and tropical zones, as well as some in industrialized countries. Three working groups have been created, which cover the following fields: (1) Vegetation Resources Monitoring and Management; (2) Geology and Natural Hazards; and (3) Urban and Environmental Planning. The second theme, "Space and Education", will be under the general direction of NASA. A number of projects are already underway and do not require large new investments. However, the process of identifying the lead and contributing organizations of each project, and of approving projects as SAFISY projects has not yet been completed. Under this theme, three working groups were established to consider projects in the following areas: (1) earth observation in education; (2) space science in education; and (3) space communications in education.

77. The third SAFISY panel, the Panel of Experts on Space Science, is organized by the international Committee on Space Research (COSPAR). The projects coordinated by this panel fall into three categories: (1) research into magnetospheric and heliospheric physics, the structure and physical state of the Sun and other solar system bodies and the problems associated with living and working in space; (2) improvements in the timely and efficient acquisition, processing and distribution of space science data; and (3) dissemination of the results of space science research to the widest possible public audience.

78. ISY activities will culminate in a number of special events at which the results of the cooperative projects will be presented. ISY meetings will also include discussions of problems and trends in space science and technology and recommendations for future research. There will also be panel sessions with media and key political figures and exhibitions on the themes of ISY. The events being planned or considered by SAFISY and its affiliates are:

(a) An ISY conference on "Earth and space science data information systems", at Pasadena, California, United States, from 11 to 14 February 1992;

(b) A European ISY conference on "Space in the service of the changing earth" at Munich, Germany, from 30 March to 4 April 1992;

(c) An ISY conference on "World Forest Watch" in Brazil, from 27 to 29 May 1992;

(d) A "World Space Congress" in Washington from 28 August to 9 September 1992;

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(e) An Asian/Pacific ISY conference, in Japan, with the theme and time to be announced.

B. International Geosphere-Biosphere Programme

79. The International Geosphere-Biosphere Programme (IGBP) is carried out within the framework of the International Council of Scientific Unions (ICSU). Along with the World Climate Research Programme (WCRP) and other international research efforts, it addresses critical scientific problems related to global environmental change. While the objective of IGBP is to understand the interactive processes that regulate the entire Earth environment system, for practical reasons a set of core projects on distinct sub-components of the system will be designed. These core projects will focus on environmental processes, involving both human and natural forces, in which current understanding is insufficient to predict environmental changes.

80. The initial phase of the programme will focus on seven key questions:

(a) How is the chemistry of the global atmosphere regulated and what is the role of biological processes in producing and consuming trace gases?

(b) How do ocean bio-geochemical processes influence and respond to climate change?

(c) How do changes in land use affect the resources of the coastal zone, and how do changes in sea level and climate alter coastal ecosystems?

(d) How does vegetation interact with the physical processes of the hydrological cycle?

(e) How will global changes affect terrestrial ecosystems?

(f) What significant climatic and environmental changes have occurred in the past, and what were their causes?

(g) How can our knowledge of the components of the Earth system be integrated and synthesized in a numerical framework that provides predictive capability?

81. These questions will be addressed through core projects, including observation of environmental parameters, through research on environmental processes and through environmental modelling. The projects have been developed by planning meetings organized by IGBP over the past two years. Currently there are a variety of suggested core projects, which are categorized by the ICSU Special Committee for the IGBP as established, proposed or potential, depending on whether they have been endorsed by the world scientific community and whether they are ready for implementation.

82. Most of the established core projects involve studies of environmental processes on continental and global scales that can be observed by remote sensing. Although a data collection strategy for the projects is only beginning to be formulated, it is clear that the data needs are going to be global, with varying temporal and spatial scales. While remote sensing data are currently widely available, data acquisition is only loosely coordinated in time and space. An international collaborative programme for the collection of pertinent Earth-system data for global change studies will require an evolving Earth-observing system in order to fulfil IGBP needs.

83. Discussions among IGBP scientists have made it clear that international satellite remote sensing capabilities, both current and planned, will play an essential role in IGBP. However, there are several impediments to the most effective use of the satellite data. Users are often remiss in predicting their data needs, so that they believe they never get what is really essential. Most collected data will therefore never be used, and the data that are used are often used in unexpected ways. Finally, data users are always under-funded, since finances are directed preferentially towards the space segment.

84. At present, there are about five operational geostationary satellites providing global data on cloud cover and cloud temperatures on a near-continuous basis. In the low polar orbits there are a number of operational remote sensing satellites, including Landsat, NOAA and SPOT, which collect a variety of remote sensing data in the visible and infrared spectral regions, which have provided more or less regular data over the last 10 years or so, including close to 6 years of global vegetation index data. In addition, there are a number of research satellites such as ERBS (Earth Radiation Budget Satellite) and Nimbus, which provide data on other parameters such as solar radiation, sea-surface temperature, atmospheric moisture, ocean chlorophyll, snow cover, sea ice extent, Earth radiation budget, ozone and stratospheric dust.

85. Such satellite data are of unique value for WCRP and IGBP, provided that they are consistent in quality and continuous over at least a decade. Only a few of the above mentioned data sets pass this test. These are the measurement of solar radiation, ozone, stratospheric dust and sea surface temperature. Efforts are now under way to reprocess old data and generate consistent global data sets for ocean chlorophyll, vegetation index, radiation budget and snow and ice cover for the 1980s. The main problem in studying long-term changes is sensor calibration. A drift in sensor response and changing algorithms for atmospheric correction can easily be interpreted as an indication of global environmental change. Without a thorough evaluation of such variations in the remote sensing systems, satellite data are of practically no use for the study of global change.

86. In the next decade, a number of new satellites with new sensors applicable to IGBP studies are planned by several countries. The challenge for the space agencies and for the IGBP community will be to ensure that the data acquired by different satellites are mutually consistent and can provide

an uninterrupted time series to document accurately long-term changes in the state of the atmosphere, ocean and land. Some data gaps are inevitable, such as a gap of at least five years on ocean colour between the Coastal Zone Colour Scanner (CZCS) on Nimbus 7, which stopped functioning in 1987, and the Sea-viewing Wide Field of View Sensor (SeaWiFS), which still has an uncertain launch date. Minimizing this data gap in ocean colour measurements is a high priority for IGBP.

87. A major development in Earth observation from space will be the launch of a series of large polar orbiting platforms starting in 1997. While the payload combinations of these platforms are still being defined, consideration is being given to observations relating to tropospheric chemistry, land surface phenomena, vegetation measures, ocean colour, sea-surface temperature, sea-surface winds and soil moisture.

88. One of the principal impediments in the use of space data by the international science community has been the inconsistency of data formats and procedures. At present, there are no consistent international policies and protocols for pricing, licensing, copyright or import/export restrictions. A substantial advance in this direction will be the development of an Earth Observing System Data Information System (EOSDIS) and an IGBP Data Information System (IGBP-DIS).

C. Global Change Encyclopaedia

89. The Global Change Encyclopaedia (GCE) project was initially developed by the Canada Centre for Remote Sensing and subsequently proposed by the Canadian Space Agency as a Canadian contribution to the International Space Year and the International Geosphere-Biosphere Programme. The objectives of the GCE project are:

(a) To increase global awareness of the value of space observations for the study of the environment, especially in the context of global change;

(b) To acquaint students, teachers, scientists and the interested public with satellite data, digital data processing (including image analysis and geographic information systems) and the use of remote sensing and ancillary data for environmental analysis, including socio-economic aspects.

90. The basic form of the Encyclopaedia will be a set of CD-ROMs (compact disc read-only memory) containing data, together with a software package, probably on separate diskettes, for manipulating the data. In addition, a subset of the data will be produced on diskettes as a demonstration package for users who do not have access to CD-ROM readers.

91. The various GCE satellite data sets will be co-registered onto a geographic database, probably defined by latitude and longitude. This will permit the user to extract easily, from the various data sets, information for a defined geographical area. To simplify processing for users, data will be

stored in a radiometrically and geometrically corrected form and will generally be processed to represent environmental parameters (e.g., ocean colour) rather than sensor data (e.g., radiance). The GCE data sets will concentrate on consistent, long-term satellite data, probably with comprehensive coverage for the 1985-1989 period.

92. The GCE satellite data will be accompanied by data from other sources, including socio-economic data on a world-wide basis, co-registered with the satellite data. These data will include such factors as population, agricultural production, energy production and consumption of non-renewable resources. Sources of such data include the United Nations and the World Resources Institute.

93. To make a link between the sometimes abstract GCE satellite data and the Earth's surface, photographs of geographic features and environmental phenomena may be included occasionally as part of the data set. These will represent such themes as endangered species in various parts of the world and will be referred to the proper geographic locations by data handling programs.

94. A software package will be provided as part of GCE to allow manipulation of single and combined data sets. The user should be able to handle data using processes such as visual display, zoom, enhancement, classification, overlays and other basic image enhancement and geographic information system operations. The system will also be able to accept, store and display annotation. Users should also be able to run their own data processing programs using the GCE data.

95. The GCE software package will make interaction possible at several levels: demonstration, browse, exercise and command. The demonstration level will be a guided tour through the GCE package. At the browse level, the user can display entire global images or a subset of global images, overlay thematic data, select data by geographic position or by data values and make composite profiles of several data layers. The user interactions at these levels must be both informative and attractive in order to maintain the interest of first-time users. Both levels will be available in diskette and CD-ROM versions.

96. At the exercise level, the user can combine various parameters by executing a series of map overlays following prompts by the program. The user will thus be able to examine relations between the parameters influencing environmental processes and phenomena.

97. The command level is intended for users familiar with the GCE package who wish to perform analyses of their own design. This resembles the command level operation of most low-cost geographic information systems. The exercise and command levels will be available only in the CD-ROM version.

98. The GCE product should be available for worldwide distribution in 1992, and the software will be available in English and French. The GCE package is intended for personal computers with a minimum configuration of a PC AT with

640K RAM, 20MB hard disk and EGA graphics card. As far as possible, the data will be in a format that could also be used with non-IBM-compatible computer systems.

III. EDUCATION AND TRAINING

99. The International Space University (ISU) is a non-profit international graduate education programme for space research and development. The first educational institution of its kind, ISU was founded in 1987 to provide graduate-level young professionals, who have demonstrated academic excellence and leadership qualities, with a summer programme embracing a broad range of space-related disciplines. The ISU Board of Directors and Board of Advisers are composed of distinguished business and government leaders, scientists, space experts and academics from many countries. ISU is supported by over 70 corporate and governmental sponsors world wide.

100. The intensive programme includes 180 hours of lectures and 125 hours of work on a project, compressing a full year of study into 10 weeks. It is designed to provide students with an opportunity to gain a general understanding of all technical and non-technical areas of importance in the exploration and development of outer space and to study and work with the world's finest educators involved in space development. The students meet peers with common interests from leading universities around the world and with whom they can discuss common goals, motivations, and ideals towards enhancing international collaboration on space development projects in the years to come. They participate in a practical design project on a topic of importance to space research and development.

101. Regardless of their academic backgrounds, students attending ISU, participate in all fields of study. The core curriculum is broad in scope and gives students an understanding of the basic principles in each discipline. In addition to the core curriculum, lectures on advanced topics are given in each field. Students spend a large portion of their time on one of the two design projects, designed to integrate coursework into a practical exercise. Student teams analyse requirements of the project and design systems to meet those requirements. At the end of the programme, the teams synthesize their design solutions into a final report.

102. Each summer until 1995, the ISU summer programme will be conducted at a prominent academic institution in a different country. It will be held in Toulouse, France in 1991, in Japan in 1992 and in Moscow in 1993. Selected course materials will be published and made available to universities and research institutions world wide.

103. In conjunction with the 1992 International Space Year, ISU should evolve into a full-year format, with Master's degree granting status, at a permanent facility suitable to the technological needs of the programme. ISU will produce textbooks and other academic materials, create tele-education courses for satellite distribution and carry out research projects. Eventually it is

hoped that ISU will have, or will negotiate access to, orbital facilities for use by faculty, researchers and students. These facilities will allow faculty and students to conduct "hands-on" research in a microgravity environment to understand fully the potential of space development for humankind.

104. In the Netherlands, the International Institute for Aerospace Survey and Earth Sciences (ITC) celebrates its fortieth anniversary this year. Founded in 1951, the Institute concentrated exclusively on transfer of knowledge in aerial survey applications to the newly independent developing countries. This provided their personnel with image interpretation and photogrammetric skills for assessing their natural resources and mapping their national territory.

105. Remote sensing methods and applications have been added to the ITC programme of knowledge transfer as they became available, and the recent development of geographic information systems is being fully incorporated. Integrated mapping, monitoring and evaluation of territory, environment and resources using aerospace survey techniques is the package offered by the Institute to participants from developing countries. About 10,000 alumni from 147 countries have graduated from ITC since 1951. It has constituted a consistent contribution by the Netherlands Government towards education for developing countries in aerospace survey applications.

106. The ITC programme emphasizes integrated application of airborne data, space observations and data from other sources. Applications covered include land and water resources, vegetation, forests, agriculture, human settlements, natural hazards and the environment. Integrated mapping, cadastral surveying and land information systems are also covered. The courses are exclusively directed towards the realities existing in developing countries.

107. The courses offered are generally at the postgraduate (M.Sc.) level, and Ph.D. level studies are included in the Institute's research programme. ITC maintains close contacts with its alumni through a network of information exchange and advisory services. A scientific journal (The ITC Journal), covering the whole spectrum of aerospace survey applications, is sent free to all alumni four times a year.

108. The Institute's offspring in the domain of remote sensing applications - which are now fully fledged education institutes - include the Indian Institute of Remote Sensing, Dehra Dun, India (since 1967), and the Instituto Geográfico "Augustín Codazzi", Colombia (initiated in 1968 as the Centro Inter-Americano de Foto-interpretación). Both institutes have intensive cooperation with ITC, and their courses are kept at the same level as those at ITC. Their postgraduate diplomas are mutually recognized as a qualification for further studies.

109. ITC also maintains close links with the Photogrammetric and Cartographic Training Institute at Bandung Technological University, Indonesia, the Wuhan Technical University of Surveying and Mapping, China, and with a large number of other institutes.

IV. SPACE ENVIRONMENT

110. The space environment around the Earth is populated by natural debris (micrometeorites) and man-made debris. The growing population of man-made debris has for some time been attracting the attention of many investigators and agencies. The main source of data on the debris population is the Space Surveillance Network operated by the United States Space Command, which at present tracks about 7,100 objects. However, this tracking network can only track objects larger than 10 cm in diameter at 1,000 km altitude, or 4 cm at 400 km altitude. Smaller debris cannot be tracked systematically with the current systems. It has been estimated that there are 20,000 to 70,000 untracked objects on the order of 1 cm in size in addition to higher numbers of smaller objects.

111. In India, a theoretical study was undertaken to model debris generation caused by the breakup of a space object or a collision between two space objects. It is estimated that remnants from such events account for nearly 44 per cent of the total tracked debris and 57 per cent of the low-orbit debris. The study could help to map the untracked debris environment and to predict collision probability with operational spacecraft.

112. Mass and velocity distribution of debris after fragmentation were estimated based on experimental observations and assuming a random distribution of a large number of small fragments. The orbital elements of individual fragments are then calculated by adding velocity increments due to the fragmentation to the velocity of the initial object. Finally, the evolution of the debris cloud is then determined by combining the evolution of the individual trajectories over a period of time. This procedure is repeated for a number of fragmentations, and the resulting density of debris at various altitudes and latitudes is determined. The results of the simulation are compared with the observed density distribution of debris, and through an iterative procedure the model is adjusted to achieve the best fit to the observed density distribution.

113. About 33 major spacecraft fragmentations, out of the 90 breakups reported so far, were simulated and compared with observations. The observed density peaks at 800 km, 1,000 km and 1,500 km are clearly noticeable in the simulation. The value of this method is that it provides a sound basis for estimating the amount and size-distribution of debris too small to be observed. The importance of such estimates is indicated by the finding that in the case of the breakup of Cosmos 1691, the trackable debris formed only 2.2 per cent of the total amount of debris. This corresponds to the results of other studies and further emphasizes the importance of preventing breakups and collisions of large objects in orbit.

114. In Germany, technical analysis of space debris related problems is conducted mainly at the Institute for Reactor Technology and Space Flight Technology of the Technical University of Braunschweig, under contract from the German Space Agency (DARA). A review of recent results is given in document A/AC.105/C.1/L.170, distributed during the session of the Scientific and Technical Subcommittee.

115. The results indicate that new ways of conducting space operations must be established at higher altitudes, where the self-cleaning effect of the Earth's atmosphere is missing. All objects placed in such orbits should be actively removed after the end of their missions, for example by an active controlled re-entry manoeuvre, and no debris should be left behind in orbit. For the next generation of the European launcher, Ariane 5, the upper-stage motor will be removed from orbit shortly after the separation of the payload by a controlled braking thrust.

116. If it is not possible within the next few decades, to limit the debris population, especially of the larger objects, active removal by retrieval missions may be the only way to reduce an unacceptably high population level. A practical removal programme would probably involve the removal of numerous large objects from higher altitudes. A strategy for such a removal, called the Tethered Remover Satellite, would use orbital energy transfer and energy transformation with the help of a space tether. The concept will be investigated in more detail in the near future in cooperation with NASA and industry. While it will probably be at least 10 to 20 years before such a remover vehicle could be operational, studies should be started now.

V. SPACE TRANSPORTATION SYSTEMS

117. In Japan, the development of vehicles for launching satellites was initiated using United States technology under a licence agreement. Since then, persistent efforts have been made to develop domestic technology. Between 1975 and 1987, a total of seven satellites, including Japan's first geostationary satellite, were launched by N-I rockets and eight satellites by N-II rockets. The development of the N-II launch vehicle involved improving the first and second stages of the N-I to increase payload capability, and introducing an inertial guidance system to improve flight accuracy.

118. Currently, the H-I launch vehicle is Japan's major "workhorse". All of the subsystems except the first stage and payload fairing were newly developed by the National Space Development Agency of Japan through independent technology. To meet expected demand for launching large-scale and high-performance satellites in the 1990s, NASDA is now undertaking development of the H-II launch vehicle. The H-II launch vehicle is being developed domestically and will be a world-standard vehicle in launch performance, capability and reliability.

119. The H-I launch vehicle is a three-stage rocket developed to launch geostationary satellites weighing about 550 kg. The first stage and strap-on boosters are the same as those of the N-II, but a high-performance second-stage engine using liquid oxygen and hydrogen propellants, a large-scale solid-propellant engine for the third stage and an inertial guidance system for its guidance control were developed by NASDA.

120. The key new component of the H-I launch vehicle is the second-stage LE-5 engine with 10 tons of thrust and a capability for restart in orbit,

which is important for boosting interplanetary probes and geostationary satellites into their trajectories. For the upper stage, an advanced high-performance solid propellant, a high-strength titanium alloy motor case and a lightweight nozzle were developed to provide low weight and high performance.

121. The H-I inertial guidance system consists of an inertial measurement unit and an inertial guidance computer. The inertial measurement unit is composed of three gyroscopes and three accelerometers that measure direction and acceleration, which are integrated to determine the position, velocity and attitude of the launch vehicle. The inertial guidance computer compares the measured trajectory with the planned trajectory, calculates navigation, guidance, and control parameters to maintain the planned trajectory and issues commands to the control system.

122. The new-generation H-II launcher, currently under development, will be capable of launching a 2-ton-satellite into geostationary orbit. It is a two-stage vehicle with two large solid rocket boosters added to the first stage. It will be also capable of sending a 9-ton payload into a low orbit and a 2- to 3-ton probe to Venus or Mars. From the economic point of view, the possibility of launching two 1-ton satellites simultaneously into geostationary orbit is very important.

123. The new LE-7 engine, which uses liquid hydrogen and liquid oxygen fuel and generates 110 tons of thrust, is being developed for the first stage. The two solid rocket boosters will provide an additional 160 tons of thrust each. Since the gimbal control of the LE-7 engine alone is not sufficient for attitude control of the vehicle, the boosters are equipped with a movable nozzle for directional control. The second-stage engine is an improved version of the restartable LE-5 engine of the H-I. The guidance control system of the H-II will be an improved version of the H-I inertial guidance system. For the inertial measurement unit, a strap-down system using a new laser gyro will be used. It is a simple mechanism involving fewer components and is smaller and more reliable than conventional systems.

VI. LIFE SCIENCES AND SPACE MEDICINE

124. The term "tele-medicine" refers to the combined use of electronic medical monitoring systems and telecommunications. The concept originated in the use of electrocardiographs and other physiological monitoring devices to monitor the vital signs of astronauts during space flight and the transmission of these measurements to the ground. Since 1971, health care systems on Earth have used space technology to provide physicians in remote areas or at small medical facilities with access to expert consultations for their patients. This combination of physiological monitoring and communications allows a dispersed population to benefit from a limited supply of highly trained personnel.

125. The 1989 "Armenia-U.S.A." medical Spacebridge and the "Ufa-Armenia-U.S.A." link represent the first use of satellite communications in support of systematic, long-term, multi-disciplinary collaboration among the medical personnel of two countries. The communications links supporting the Spacebridge between various United States medical centres and Yerevan, Armenia, used a combination of domestic and international satellites and terrestrial networks, communications facilities and services. The exercise was evaluated as highly successful and worthwhile, and the experience gained will be used in future.

126. Some 3.2 billion people - over half the world's population - live in areas with active anti-malaria programmes, and over 100 million new cases of malaria occur every year. Predicting the time and place of mosquito outbreaks is the key to the control of malaria epidemics, and NASA's Malaria Project is intended to develop this capability. Remote sensing technology is used to identify the habitats in which mosquitoes will breed and to estimate the timing of breeding weeks or even months before the mosquito population increases.

127. Based on the results of such experiments, the feasibility of a MedSat satellite is being studied. The satellite would be equipped with sensors operating in the visible and infrared spectral bands, with radar and with data handling and communications systems. Through the use of tele-medicine links, the efforts of field investigators at remote sites can be coordinated with experts in academic, epidemiological, clinical, and public health laboratories.

128. The NASA Controlled Ecological Life Support System (CELSS) programme was initiated in 1978 to improve space life-support systems to allow for long-duration missions. The goal of the programme is to develop safe and reliable systems which will produce palatable food, potable water and a breathable atmosphere by recycling metabolic and other wastes. The central feature of CELSS is the use of photosynthesis by green plants to produce food while generating oxygen and removing carbon dioxide.

129. Results to date indicate that common field crops have a potential productivity much greater than present productivity. With current methods, approximately 1 acre of crop is required to produce sufficient food energy for one person per harvest. Using wheat, CELSS experiments in controlled environments reduce that requirement to 0.002 acres per person (500 people per acre), and crops grown under these conditions are of higher quality, with almost twice as much protein, and give predictable yields.

130. Although some CELSS techniques, such as enriching the carbon dioxide in a closed atmosphere, are not applicable in open fields, the knowledge gained from this research will be of great value. The design of small, efficient plant growth chambers may also be practical in urban areas, in regions where growing conditions are not suitable for particular crops or in extreme environments such as the Antarctic or deserts. NASA has also built a large, closed chamber for studying plant growth and behaviour. The chamber has 34 sensors continuously measuring 10 environmental parameters in various parts of

the chamber. Research is also being conducted on the conversion of inedible plant material into food products. Wheat, for example, contains 60 to 65 per cent of inedible biomass, which in principle could be converted into food products through the use of micro-organisms and enzymes.

131. A critical area in greenhouse food and flower production has been the cost of artificial illumination. NASA is studying new technology for energy-efficient lighting systems that will have broad non-space applications. Systems based on the use of light-emitting diodes are highly efficient since all of their light energy is emitted in the regions of the spectrum that best promote plant growth. The CELSS programme is also looking into automation and robotics techniques for growing and harvesting plants in space. These automated methods may be of value for hydroponic farming, which could increase productivity by increasing the level of automation.

VII. ASTRONOMY AND PLANETARY EXPLORATION

132. The United States plan for satellite astronomy and astrophysics includes several complementary sets of science activities. Four Great Observatories will provide orbital observations across the electromagnetic spectrum with high sensitivity and with high angular and spectral resolution. The first in the series, the Hubble Space Telescope (HST), was built in cooperation with the European Space Agency (ESA) to provide the international scientific community with observations, unhampered by atmospheric distortion, in the near infrared, visible and ultraviolet regions of the spectrum. The observational programme and distribution of data is being managed by the Space Telescope Science Institute in Baltimore and its international staff.

133. Although a flaw in the shape of the primary mirror was discovered soon after the Space Telescope was launched in April 1990, the flaw's effect on observations has been less severe than was first feared, and computer image processing methods have been used to improve the images. The resulting data are far better than that provided by any other telescope and have already contributed to a number of major discoveries. A servicing mission by Space Shuttle astronauts in late 1993 is expected to restore the Telescope to its original design specifications.

134. The Gamma Ray Observatory (GRO), second in the Great Observatories series, was successfully launched in April 1991 from the Space Shuttle Atlantis. During the release of the spacecraft from the Shuttle, extravehicular activity by the astronauts was required to correct a problem encountered during deployment of the communication antenna. Similarly, during the December 1990 flight of the Space Shuttle Columbia carrying the Astro-1 ultraviolet telescopes, the astronauts overrode a faulty computer-based orientation system and were able to accomplish most of the planned observations.

135. The 17-ton Gamma Ray Observatory has four gamma-ray detectors and will conduct the first comprehensive survey of sources of high-energy gamma rays.

Germany furnished the Compton Telescope (COMPTEL) as well as key portions of the Energetic Gamma-Ray Experiment Telescope (EGRET), while the United States provided the Oriented Scintillation Spectrometer Experiment (OSSE) and the Burst and Transient Source Experiment (BATSE). Since the universe is largely transparent to gamma rays, GRO should be able to probe the centre of our Galaxy for the first time and identify black holes by measuring the characteristic gamma radiation emitted from their surrounding material. GRO is designed for orbital refuelling, so that its operational lifetime could extend beyond the turn of the century.

136. The third and fourth Great Observatories, the Advanced X-Ray Astrophysics Facility (AXAF) and the Space Infrared Telescope Facility (SIRTF), promise to improve vastly upon previous observations in those parts of the electromagnetic spectrum when they are launched later during the current decade. Scientists from the United Kingdom of Great Britain and Northern Ireland and the Netherlands will join United States participants in designing experiments for AXAF, which is to have much greater capacity for spectroscopy than any previous X-ray mission.

137. The next major component in the United States space exploration plan is the Explorer programme, consisting of smaller spacecraft, designed to fill specific gaps in our understanding of the universe. Two recent successes in this programme are the Roentgen Satellite (Rosat), a cooperative effort with Germany for surveying X-ray sources, and the Cosmic Background Explorer (COBE). Evaluation of data from COBE has already provided strong confirmation of the Big Bang theory, but has raised new theoretical problems concerning the origin of large-scale structures in the universe. The development of new sensors for future astrophysical missions is supported through grants and suborbital missions.

138. An important part of United States space astronomy programme is the dissemination, analysis and publication of data and results. The international scientific community is invited to participate in the use of this data, which is disseminated through Astronomical Data Centres around the world. Through NASA's international network, data can be sent from the Goddard Space Flight Center to centres in all continents via satellite. Data are distributed to users in the form of printed images or catalogues, magnetic tapes, compact discs (CD-ROM) or digital audio tapes.

139. The Magellan spacecraft entered into orbit around Venus in August 1990 and has been systematically mapping the planet by radar since then. The spacecraft has provided much new information about the surface of Venus, including features as small as 100 metres across. During its primary mapping survey, Magellan will orbit Venus for 243 days (equivalent to one Venusian day) and collect data from 90 per cent of the planet's surface. The Magellan project has involved cooperation with scientists from Australia, France, the United Kingdom and the USSR. A special data management and archive team has been established by NASA to manage the large quantity of data products, including magnetic tapes, photographs, optical discs, maps and hard-copy listings, that will result from the Magellan mission.

140. Magellan has enough fuel to maintain the orbit and attitude of the spacecraft for at least seven additional 243-day cycles, allowing more detailed study of areas of particular interest. In addition to the radar images, information on the planet's gravity field, reflecting the distribution of mass within it, can be derived from orbital perturbations.

141. The Galileo spacecraft for exploring Jupiter is a joint NASA-German effort with substantial cooperation from Canada, France, Sweden and the United Kingdom. The spacecraft, on its complex trajectory to Jupiter, made the first of two gravity-assist manoeuvres around Earth in December 1990 during which the sensors made observations of the Earth-Moon system. Those data are being used primarily for the calibration of instruments, but they also provided new information about our own planet.

142. During its flight over Antarctica, Galileo's instruments observed the clouds that appear to act as catalysts in the chemical reactions that destroy ozone, creating an "ozone hole" every year. Galileo also made measurements of the total water content of the Earth's upper atmosphere, which is an important parameter in studies of climate change, and of nitrous oxide, methane and oxygen, which are products of biological activity. Speeding past the Moon, Galileo provided data on the composition of the lunar crust and sent back photographs of previously poorly mapped areas of its far side.

143. In October 1991, Galileo will reach the asteroid belt between Mars and Jupiter and will observe the asteroid Gaspia from a distance of about 1,000 km. Galileo will receive its final gravitational boost from the Earth during the second encounter in December 1992 and is scheduled to reach Jupiter in December 1995. It will drop an instrumented probe into the Jovian atmosphere and then enter into orbit around Jupiter to conduct at least 22 months of observations of the planet and its 16 moons.

144. In October 1990, the Space Shuttle Discovery deployed the Ulysses interplanetary spacecraft developed by the European Space Agency (ESA) to make the first observations of the polar regions of the Sun. The probe is now heading towards Jupiter where it will use the strong gravity field of the giant planet to swing it out of the plane of the solar system and into a trajectory passing over the solar poles. It is scheduled to arrive at Jupiter in February 1992, to fly over the south pole of the Sun in 1994 and over the north pole a year later. As a result of precise trajectory control, Ulysses will have enough fuel for a second orbit around the Sun.

145. As part of NASA's Planetary Observer programme, a new class of spacecraft for exploring the inner solar system is being developed. A Mars Observer is to be launched in September 1992 to orbit Mars and conduct a detailed long-term study of that planet. The Mars Observer will also transmit data from two Soviet Mars-94 probes, each of which will include an orbiter and lander with aerostats, penetrators and a small rover vehicle. The United States Lunar Observer, currently scheduled for launch in 1997, will undertake a long-term survey of the Moon, providing a wider scientific context for interpreting the detailed local data obtained during the Apollo lunar landings.

146. The Cassini probe to Saturn and the Comet Rendezvous-Asteroid Fly-by (CRAF) spacecraft will be the first United States spacecraft to explore smaller bodies and the outer solar system. Cassini, a joint project with ESA scheduled for launch in November 1995, will conduct a comprehensive investigation of the Saturn system during at least 60 orbits around that planet. As part of the Cassini mission, the Huygens probe, to be provided by ESA, will descend into the thick, cloudy atmosphere of Saturn's largest moon Titan in order to analyse the atmosphere and observe the surface. Cassini will also fly by the asteroid Clarissa. The CRAF spacecraft, a joint NASA-German project scheduled for launch in February 1996, will fly in tandem with the comet Tempel 2 for a while and then examine the large asteroid Mandeville. To allow a heavier scientific payload, both Cassini and CRAF will use the gravity fields of Venus and the Earth to gain extra velocity towards their final destinations. With the completion of these missions, all the major planets of our solar system will have been explored in detail with the exception of Pluto, which is being considered for a later visit.

Appendix

LIST OF SCIENTIFIC AND TECHNICAL PRESENTATIONS

I. SPECIAL PRESENTATIONS ORGANIZED BY COSPAR AND IAF

Symposium on applications of airborne and satellite remote sensing for prospecting mineral and groundwater resources and for monitoring and managing biological resources, with emphasis on agriculture, taking into particular account the needs of developing countries.

Session 1: Geological, Mineral and Water Resources, Wednesday, 20 February.
Chairman: Prof. George Ohring, Chairman, COSPAR Commission A on Space Studies of the Earth's Surface, Meteorology and Climate.

Applications of Remote Sensing for General Geology, Oil and Mineral Resources. Dr. James V. Taranik, Desert Research Institute, University of Nevada, United States.

Applications of Remote Sensing for Water Resources. Mr. Massimo Menenti of the Winand Staring Centre, the Netherlands.

Applications of Remote Sensing for Mineral Resources. Mr. Lawrence C. Rowan, United States Geological Survey.

Remote Sensing: New Capabilities for the Study of Natural Resources.
Mr. Nikolay V. Mezhelovsky, USSR Ministry of Geology.

Session 2: Biological and Agricultural Resources, Thursday, 21 February.
Chairman: Mr. Dale Fester, Vice-President, IAF.

The Global Change Encyclopaedia: A Project for International Space Year.
Mr. Réjean Simard, Canada Centre for Remote Sensing.

Applications of Remote Sensing for Deforestation.
Dr. Roberto Pereira da Cunha, National Institute for Space Research (INPE), Brazil.

Applications of Remote Sensing for the Management of Land Resources.
Dr. M. G. Chandrasekhar (on behalf of Prof. U. R. Rao), Indian Space Research Organization.

Applications of Remote Sensing for Agricultural Resources.
Mr. Edwin I. Cissel, United States Department of Agriculture.

The International Geosphere/Biosphere Programme: The Challenge for Remote Sensing. Dr. John R. G. Townshend, Department of Geography, University of Maryland, United States.

II. OTHER SCIENTIFIC AND TECHNICAL PRESENTATIONS

Progress towards the Permanent ISU Campus in 1992. Mr. Todd Hawley, International Space University.

COSPAR/IAF World Congress 1992. Mr. James Harford, IAF.

Voyage to the Planets. Dr. Wesley T. Huntress, United States National Aeronautics and Space Administration (NASA).

The United States Space Shuttle Programme: Experience from Flight STS-35. Astronaut Vance Brand, NASA.

Use of Weather Satellites for Environmental Monitoring. Mr. Dan Tarpley, United States National Oceanic and Atmospheric Administration (NOAA).

Life Sciences and Space Medicine. Dr. Arnauld Nicogossian, NASA, and Academician Oleg Gazenko, Institute of Medical and Biological Problems, USSR.

From the Universe to the Laboratory: Using Space Data for Research and Education. Dr. Gunther Riegler, NASA.

Space Development Activities of Japan. Mr. Sinichi Nakayama, Science and Technology Agency, Japan.

Airborne Remote Sensing for Global Resources Monitoring: A Summary of Canadian Capabilities. Ms. Diane Thompson, Canadian Remote Sensing Society.

Transfer of Knowledge on Remote Sensing Applications to Developing Countries. Dr. Jan J. Nossin, International Institute on Aerial Survey and Earth Science (ITC), the Netherlands.

Space debris. Dr. M. G. Chandrasekhar, Indian Space Research Organization.

SAFISY Activities. Dr. B. Pfeiffer, Secretariat for the Space Agency Forum for International Space Year (SAFISY).

International Space Year - World Forest Watch (WWF) Programme. Dr. Roberto Pereira da Cunha, National Institute for Space Research (INPE), Brazil.



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THIRTIETH REPORT BY THE INTERNATIONAL TELECOMMUNICATION UNION
ON TELECOMMUNICATION AND THE PEACEFUL USES OF OUTER SPACE

Note by the Secretariat

A progress report on telecommunication and the peaceful uses of outer space has been submitted by the International Telecommunication Union (ITU) for the attention of the Committee on the Peaceful Uses of Outer Space. The report is available in English, French and Spanish only, and in view of the limited number of copies received, it is distributed to the members of the Committee only.
